1984 DOE AUTHORIZATION
(Transportation Programs)

HEARINGS

BEFORE THE

SUBCOMMITTEE ON TRANSPORTATION,
AVIATION, AND MATERIALS

OF THE

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SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

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1984 DOE AUTHORIZATION

WEDNESDAY, FEBRUARY 23, 1983

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
SUBCOMMITTEE ON TRANSPORTATION,
AVIATION AND MATERIALS,
Washington, D.C.

The subcommittee met, pursuant to notice, at 2:05 p.m., in room 2325, Rayburn House Office Building, Hon. Dan Glickman (chairman of the subcommittee) presiding.

Present: Representatives Glickman, Carney, Boehlert, and McCandless.

Mr. GLICKMAN. The subcommittee will be in order.

Why don't we go ahead and start, and if Mr. Carney comes, or anybody else, they can have the opportunity to put in an opening statement.

I would like to welcome you back to the committee, Mr. Tribble.

Today the subcommittee will begin 2 days of hearings on the Department of Energy's budget request for vehicle and engine research and development.

These programs were created largely by two pieces of legislation that began in this committee. So we are particularly interested in monitoring their progress.

The budget request for fiscal year 1984 is $40.9 million, which is considerably less than the Congress appropriated for the current year. But it is much better than the zero request we received last year, and it does seem to represent a grudging recognition that the Government has a role in supporting long-term research and technology in the automotive field.

Nevertheless, we cannot afford to be lulled by current events in the international oil market. OPEC and the others may find it necessary to reduce prices over the short run, and we may experience some temporary relief at the pump. But once the world's economy begins to recover, demand will surely rise and prices will certainly go back up again.

The long-term trend hasn't changed. Our economic well-being, as well as our national security, is still highly dependent on the whims of a few countries in a turbulent part of the world. The wisdom shown by those who drafted both the Electric Vehicle Act and the Automotive Propulsion Act is as valid today as it was then. We must still provide for the day when alternative propulsion systems and alternative fuels will be needed, and such a day could just as easily come sooner rather than later.

Unfortunately, this budget seems to say just the opposite. It seems to say the energy crisis is over. We can all relax; there is no need to worry about the future. After all, nobody had any trouble buying gas this morning, did they? There were no lines. Prices are even coming down. But what about next year?

To me, one of the great ironies of our age is our willingness to spend many billions to prepare for a war to protect our sources of oil, but our unwillingness to spend even a few million to find alternatives for that oil.

This budget is a dramatic reflection of that irony. Its principal characteristic is retrenchment—retrenchment not only from a host of new opportunities, but also retrenchment from some very promising ongoing work.

I have in mind the Stirling engine project. Despite excellent progress toward meeting its legislative goals, and despite the clear intention by Congress to complete it, the Stirling engine project is once again scheduled for termination.

I say once again because the Department has tried this ploy twice before, and twice before the Congress has rejected it. I suspect there will again be strong support for restoring the program. In the meantime, it will continue to suffer the interminable disruption caused by the Department's recalcitrance in carrying out congressional instructions.

I am sure that Mr. Carney will have a statement, and it will be included in the record immediately following mine.

As I said, it is a pleasure to welcome you here, Mr. Tribble. You may feel free to summarize or read your statement at your pleasure. It will be included in its entirety in the record.

Before we begin, I'd like to ask whether Mr. Carney has an opening statement.

Mr. **Carney**. I do have an opening statement, Mr. Chairman.

I am going to have to apologize; we have a very, very unique situation going on in the Merchant Marine and Fisheries Committee, and that is, under the public law that we passed in the 96th Congress, we as a committee determine the responsibility of how we are going to give people compensation for accidents in canals.

So we are right now acting as judge and jury, and it would be most inappropriate for me as the ranking member of that committee not to be there for that entire testimony. We carefully scheduled this committee meeting today so I could be here, and, unfortunately, for the testimony, there are some experts from Norway there, and we have to continue through the afternoon.

So I apologize. I will stay for as long as I possibly can, but when I duck out, you will know why.

Thank you.

Mr. **Glickman**. Mr. McCandless, do you have anything you would like to say before we begin?

Mr. **McCandless**. No. Thank you, Mr. Chairman.

Mr. **Glickman**. All right. Mr. Tribble, why don't you proceed?

[Statement of Hon. William Carney follows:]

OPENING STATEMENT
HON. WILLIAM CARNEY
HEARING ON AUTOMOTIVE R&D
FEBRUARY 23, 1983

THANK YOU. MR. CHAIRMAN. I JOIN WITH YOU AND MY COLLEAGUES IN WELCOMING MR. TRIBBLE BEFORE OUR SUBCOMMITTEE TODAY.

THE DEPARTMENT OF ENERGY HAS CERTAINLY GONE THROUGH A NUMBER OF GROWING PAINS SINCE ITS INCEPTION IN 1976. WE SAW EXTENSIVE REORGANIZATION OF PRIORITIES WHEN THE CURRENT ADMINISTRATION CAME INTO OFFICE IN 1980. DOE HAS NOW BEEN RESTRUCTURED INTO A LEANER, MORE AGGRESSIVE ORGANIZATION THAT IS PERFORMING IN AN APPROPRIATE GOVERNMENT ROLE; NAMELY, LONG TERM, HIGH RISK RESEARCH AND DEVELOPMENT THAT INDUSTRIES WILL NOT UNDERTAKE BY THEMSELVES.

THE TRANSPORTATION PORTION OF DOE'S BUDGET REPRESENTS THOSE PROGRAMS THAT WILL PROVIDE ALTERNATIVES TO OUR OIL-DEPENDENT ECONOMY. ELECTRIC AND HYBRID VEHICLES, ALTERNATIVE FUELS, ADVANCED MATERIALS DEVELOPMENT, AND THE VEHICLE PROPULSION R&D IN ADVANCED AUTOMOTIVE GAS TURBINES AND STIRLING ENGINES; ALL OF THESE PROGRAMS WILL HELP TO INCREASE THE FUEL EFFICIENCY OF THE U.S. TRANSPORTATION SYSTEM, AS WELL AS ALLOW AN ENVENTUAL SWITCH FROM PETROLEUM TO ELECTRICITY AND ALTERNATIVE FUELS.

THE $41 MILLION REQUESTED BY DOE FOR THE FISCAL YEAR 1984 TRANSPORTATION BUDGET WILL ALLOW THE AGENCY TO CONTINUE THEIR WORK IN THE VARIOUS CRITICAL PROGRAM AREAS THAT I MENTIONED. THE EMPHASIS, OF COURSE, WILL BE IN TECHNOLOGY DEVELOPMENT RATHER THAN PRODUCT DESIGN. AND, OF COURSE, IT WILL BE OUR RESPONSIBILITY TO DETERMINE WHICH TECHNOLOGIES HAVE BEEN DEVELOPED TO THE PROPER EXTENT WHERE INDUSTRY SHOULD CARRY THEM ON TO PRODUCT DEVELOPMENT.

STATEMENT OF JOSEPH J. TRIBBLE, ASSISTANT SECRETARY, OFFICE OF CONSERVATION AND RENEWABLE ENERGY, U.S. DEPARTMENT OF ENERGY

Mr. **Tribble**. Thank you, Mr. Chairman and members of the subcommittee. It is a pleasure for me to be here today to discuss with you the programs under my supervision through which we attempt to improve the efficiency with which we use energy in the transportation sector.

In my testimony today, there are several charts that I think you may find interesting, and I would like to discuss each one of them very briefly. They are in the back of the copy of the testimony that you have.

The first one is a chart of the U.S. imports of oil. This shows the importation of oil, both from non-OPEC sources, from total OPEC sources, and from Arab OPEC sources from 1960 through 1982.

We have also obtained the latest total import figures for the 4 weeks ending February 4, 1983, and have shown them on the chart to indicate the continuing trend.

There has, of course, been a dramatic decline in the importation of oil into the United States since it peaked in 1977. As of February 4, 1983, gross imports were 4.3 million barrels per day. The relatively low level of imports in the latest figure is the result of many factors. We believe, however, that the two most important factors are the conservation which has taken place and the reduced economic activity.

The next chart, entitled "Conservation," depicts the growth rate in energy consumption for two periods. The first period is from 1951 through 1973. The second period is from 1973 through 1981.

The table indicates a negative growth rate from 1973 through 1981, despite the fact that the gross national product did in fact grow at an average rate of 2.3 percent during this same period.

It is difficult to separate the progress that has been made due to conservation efforts and the reduction in energy consumption because of current economic circumstances. However, we do have a number of figures which help make this distinction.

For example, the consumption of energy in the industrial sector has improved by 20.8 percent per unit of production since the base year of 1972 in the 10 most energy-intensive industries. Residential energy consumption has been reduced by 15 percent since 1972 on a per-household basis. For the reduction in energy consumption in the transportation sector, I would refer you to the next chart.

The dashed line shows fuel economy standards as provided for in legislation. This is the mandate under which the automotive industry is working. One can see that the new car fuel economy has been ahead of the legislative mandate, and on-the-road new car fuel economy has tracked the mandated fuel economy quite well.

One of the major automobile manufacturers, in its current advertising, boasts of the fact that fuel economy has been doubled since 1973.

The lowest graph line on this chart shows the average fleet fuel economy. We expect it to continue to improve as the old automobiles presently in the fleet are replaced by those which have a much better fuel economy.

The next chart shows how this improvement in energy efficiency has come about. There is, of course, a striking correlation between the price of fuel and the actual demand. The most important factor is the improvement in automobile miles per gallon due to application of existing and new technologies. On the chart, there is a footnote that goes into some more detail as to just what is included in those categories.

This evidence indicates that energy producers and consumers have both the ability and the incentive to pursue energy conservation vigorously in response to higher energy prices.

The program we have proposed for 1984 is based on our view that the Federal role should be focused on support of longer term technology-base R&D that industry cannot reasonably be expected to support because the economic benefits are too distant and uncertain.

In 1978, when the importation of oil was near its alltime high and there appeared to be limited measures that the United States could take to reduce its dependency on imported oil, the Automotive Propulsion Research and Development Act of 1978 was passed. This legislation is the genesis of most of the transportation program now being conducted by the Office of Conservation and Renewable Energy. I would like to review with you the main components of that program.

The objective of the automotive gas turbine engine program is to provide the automotive industry with proof-of-concept components for gas turbine engine technology that will demonstrate the potential for at least a 30-percent improvement in miles-per-gallon over comparable conventional engines, while meeting emission and noise standards.

To date, two industrial teams have designed and built all-metal gas turbines of a size suitable for automotive use. There remains some test and evaluation work on engine dynamometers of both contractors' designs of the all-metal engine.

During 1983, an assessment will be made of the technical progress and accomplishments of both teams, which will lead to a selection of one contractor. Further progress in this program will depend on the success of designing and installing ceramic parts for the high-temperature section of the engine. Clearly, the challenge which is ahead is to design, produce, and test ceramic components.

We have requested $12 million for fiscal year 1984. With these funds, we expect to go forward with the ceramic component development, perhaps for both contractors, but we would also support the winning contractor in installing and testing ceramic components in the present all-metal engine which would be used as a test bed.

Efficiency of heat engines is limited by the ability of known materials to withstand stress under high temperature. This is also a barrier to high energy efficiency in many industrial processes. For that reason, a high-temperature materials laboratory has been proposed to be built at Oak Ridge National Laboratory. The purpose of such a facility is to provide appropriate space and equipment to conduct research designed to provide an understanding of material properties at elevated temperatures.

It is intended that the materials to be studied will be directly related to high-temperature materials needed for advanced energy systems. It would build on the already substantial expertise which exists at Oak Ridge in high-temperature material work.

Our request includes $9 million—$2.8 million for initial design, $6.2 million for construction—for this purpose. Total estimated cost is $20.6 million. Also included is a request for $1.5 million for continued advanced material research in this area.

Another part of our program deals with improving the energy efficiency of heavy duty diesel engines. The approach to this has been to use the waste heat in a way which would contribute to the power generated. It has now been demonstrated that efficiency improvements can be obtained with turbo compounding and also with an organic Rankine bottoming cycle using waste heat.

Both of these modifications of the diesel engine add cost and complexity to the engines and will have to wait for adequate economic justification before they are widely utilized. Further improvement in the diesel engine operation will depend upon the ability to operate at higher temperatures. Here again, ceramics will play an important part.

In addition, it will be necessary to develop new materials for bearings or other innovations which will accommodate the higher temperatures. Our request for $2.6 million in the 1984 budget will enable us to continue work in these areas.

One other aspect of our program is to encourage the use of alternative fuels in current and advanced automotive propulsion systems. Since the inception of this program, a great deal of progress has been made in establishing the use of ethanol and methanol primarily as octane enhancers. There are also a number of automobiles burning straight methanol which are in current use. The use of methane has been feasible for many years.

I might digress from the written testimony here to point out that we are planning to go forward with additional work relative to the use of methane in looking for adsorbent materials whereby we can reduce the pressures that are required in the vessels that would carry the methane onboard the vehicle.

One of the more important projects for the future is to solve any problems that may exist when using fuel from synthetic crude in current or modified engines. We have funded facilities for preparing small quantities of future synfuels for test purposes. The budget request for fiscal year 1984 is $4 million for activities in the area of storing methane and the work with the synthetic fuels.

We have also asked for a $500,000 to continue the publication of the Gas Mileage Guide.

Still another project that has been ongoing is the adaptation of the Stirling engine for automotive use. The U.S.-built MOD I all-metal engine has been successfully assembled and tested. Further improvements in this engine will depend largely upon the adaptation of new materials and designs to such parts as piston ring seals, regenerators, and the combustor.

At the committee's direction, attempts were made to find companies within the industry that would be willing to test, at their own expense, Stirling engines which were furnished to them by DOE. In response to a notice in the Commerce Business Daily, the Cummings Engine Co., Inc., has expressed an interest. NASA is continuing to contact other potentially interested companies. Since this was written, we have received letters expressing an interest both from John Deere Co. and General Motors. These were letters that merely expressed an interest and stated that additional decisions would have to be made in both companies before they could make a move toward negotiations, but nevertheless, they have indicated an interest.

We feel that by the end of fiscal year 1983, sufficient technology development will have been accomplished, and adequate test data collected, to permit the automotive industry to make a rational assessment of the potential of the Stirling engine for automotive propulsion systems. Consequently, we have requested no funds in fiscal year 1984 for continued development of that engine.

The last part of the program that I would like to discuss is the electric vehicle. It has been known for some time that the successful development of an electrical vehicle depends very much on the ability to build a battery with sufficient energy density, cycle life, power density, and low cost.

The User Task Force of site operators continues to operate the vehicles in the fleet and report data on their operation. As problems arise, they bring these problems to our attention, and we make efforts to find ways to solve them. As new developments are produced, we assist in their installation and testing.

It appears that considerable progress will have to be made in battery technology before the electrical vehicle will become a practical alternative. Continued battery development is therefore where we would expect to spend the majority of the $9.5 million that has been requested for our fiscal year 1984 budget.

Mr. Chairman and members of the committee, this concludes our formal testimony. We would be pleased to attempt to answer any questions that you have.

Mr. Glickman. Thank you very much, Mr. Tribble.

I would like for a moment to go through your budget. I have a copy of it. It is in your statement at page 8.

Mr. Tribble. All right.

Mr. Glickman. The first item, vehicle propulsion R&D, in 1982, the fiscal year appropriation was $33,500,000; fiscal year 1983 was $35 million; and you are requesting $16,100,000.

Now, I wonder if you might be able to state for the record what you are including and what you are not including that we had in fiscal year 1983. Basically, what are you dropping, and what are you keeping? I am going to run through all of the items to make sure that we get for the record exactly what you are going to be proposing and what you are not proposing.

Mr. Tribble. All right. Suppose we take them item by item and look first at the automotive gas turbine. We would anticipate, in 1984, to go forward with ceramic development assistance for both the engines, but to narrow, after fiscal year 1983, to one contractor. We would help the winner implement the use of the ceramic parts in the test-bed engine, but we would not go that distance with the one who was dropped.

So while at the present time we have the all-metal engines, they do need some further testing and some further work, really, before we can put those ceramic parts in. But we would go forward with the development of the ceramic parts and put them in the engines, provide them for both contractors, assist in testing them with one.

Mr. GLICKMAN. All right. And what do you save by going with one contractor as opposed to two?

Mr. TRIBBLE. We have been told by NASA that to go with two would cost an additional $12 million. That is kind of hard to understand, I'll have to agree, but that is the answer, so far as I know.

Mr. GLICKMAN. All right.

Mr. TRIBBLE. And we would continue research on the ceramic components themselves, also, and we have set up $2 million for that. That would be in the gas turbine program component.

Now, this vehicle propulsion R&D, of course, includes heavy-duty transport and a number of the other things. In the heavy-duty transport, we would continue research on new concepts for high-temperature waste heat recovery, and we have put $1 million in for that.

Mr. GLICKMAN. I just want to make sure. Are you reading basically from the Congressional Budget Request, fiscal year 1984?

Mr. TRIBBLE. Yes, that is right.

Mr. GLICKMAN. I want to make sure that we have the same basic numbers there.

Mr. TRIBBLE. Right.

Mr. GLICKMAN. So why don't you continue, then, because we have that in the record.

Mr. TRIBBLE. All right.

One of the problems with the improvements in diesel engines is that, in order to make a major step forward, it would be necessary to go to higher temperatures. In doing so, we will perhaps have to get away from the conventional lubrication of bearings. We may have to go to solid lubricants or air bearings or things of this nature. There is a considerable amount of research that needs to be done. We do not expect that the $800,000 that we have for that will give us the final results at all, but it is enough money to begin and carry forward investigation into those types of problems.

The development of high-temperature insulating materials, including ceramic composites, we have $800,000 in for that.

We did not put any money in for the Stirling on the assumption that we would have the two engines for industries to test. Actually, they will not begin that testing until sometime late this year, and it will probably be late next year before they have the results of the tests. But we feel that, at the end of that time, enough development will be done so that if there is an engine manufacturer who is interested in carrying forward that technology, they will be able to evaluate it.

Mr. GLICKMAN. And you think the technology is ready to go in terms of the work that the Government has done?

Mr. TRIBBLE. It is our understanding that the next step in this development would be a major effort to reduce weight. The present weight-to-horsepower ratio, as you know, is still too high for it to be included in an automobile. It does not compare very favorably with the internal combustion engine.

The next step would be a substantial one, almost a redesign of the entire engine to down-size certain components, modify the crankshaft, and get the weight ratio down. We are told that that next step will cost on the order of $40 million, and we just very honestly feel that at this stage of the development of the engine, this would be inappropiate. We have come forward, it does work; by the end of 1983 we will have some 2,000 hours of testing behind us. So, with that and the testing that the industries will do, we feel that there will be a good enough knowledge base so that if anyone is really interested in using it, he could pick it up at that point.

Mr. Glickman. All right. Looking at the summary of changes that is on page 41 of your DOE document, your big reductions from 1983 are the two automotive programs. Ending the Stirling is $13 million down from 1983, and going to one development team instead of two on the turbine engine is down $6.5 million. Is that a fair statement?

Mr. Tribble. Right.

Mr. Glickman. And you add moneys back in for a new lab, and there is an assortment of additional, smaller changes there. But we are talking about essentially $20 million down on the automobile-related proof of concept in Stirling and gas turbine, and we are up in a few other things.

Mr. Tribble. Right.

Mr. Glickman. Why don't you tell me about your work in electric and hybrid vehicle R&D? I notice you are dropping about $4.5 million in that. How is that?

Mr. Tribble. The things that we have learned from the electric vehicle program thus far are that, of course, the vehicle is no problem. The drive train is, to some degree. We have already financed and are going forward with the development of an AC motor, a transaxle motor.

There will need to be some additional work on the batteries to adapt to that. But the key to the success of the electric vehicle will be the battery. We have $9.5 million, I believe, in there, principally for battery work.

If we can come up with a battery that would give us adequate range and performance, it will be a relatively simple matter to put it in a vehicle. But at this time, that is the key to further development or further improvement. That plus the change to the AC motor are the principal parts of the program that we think we should emphasize. When we get that solved, we think we will have, then, an electric vehicle.

Mr. Glickman. I want to talk for a moment about the advanced materials development for which you show $10.5 million this year.

The first question is, Why does this appear in the transportation part of the conservation budget, and why does it appear in the conservation budget at all? There is some thinking that maybe you included it in there to make conservation look somewhat larger than it is.

Mr. Tribble. Well, this program has its inception in the basic energy sciences. It has been discussed as being a part of that activity.

Actually, the ceramics that will be developed will have probably as much application in the transportation industry as in any other industrial segment, although there will be many industrial processes that will benefit from our ability to move to higher temperatures and build materials that will accept high stress at high temperatures.

Mr. **Glickman**. Now, is all of the budget being funded by the transportation program, or is it split within the Department's budget?

Mr. **Tribble**. It is not split. The only funds that are proposed for that in fiscal year 1984 are in the transportation budget, $9 million.

Mr. **Glickman**. Now, are you coordinating this with the NASA Lewis Center, because they do so much of your ceramic work right now? I am told, for example, that at the time this was prepared, there was not very good coordination; that is, they didn't even know about it.

Mr. **Tribble**. I think that is exactly right. Certainly they would be brought into the development of this, particularly when we get ready to put ceramic parts into their programs. But the facility itself would be anticipated to be at Oak Ridge.

They do have a base of substantial expertise in high-temperature materials work there at Oak Ridge, and that is the intent.

Mr. **Glickman**. Is the Department proposing a major investment in the materials-related function at the University of California, at the Lawrence Berkeley Laboratories and is it in the materials area? And, is the Oak Ridge facility different in its orientation than the Lawrence Berkeley facility?

Mr. **Tribble**. I have to say that I am not familiar with the facility that is planned for Lawrence Berkeley, but I have been told that yes, this is certainly a different facility for an entirely different purpose. This would be dealing with not only ceramics but also alloys that might very well permit us to go higher in temperature and stress.

Mr. **Glickman**. This committee has jurisdiction over materials, and I am not concerned that we are doing work in materials. I think it is critical. I am just concerned that there is some relatively sensible coordination of the variety of materials work that is being done by the National Science Foundation, NASA, and you. At some point, I think we are going to need a fairly serious justification for each one of these new initiatives in materials.

Mr. **Tribble**. Surely.

Mr. **Glickman**. I would hope that before we mark up a Department of Energy bill this year, we can have that kind of justification.

Mr. **Tribble**. All right. We will certainly provide that for you. That is certainly a fair question. We should not be doing the same thing in two places.

[Requested justification follows:]

COORDINATION OF MATERIALS ACTIVITIES AND FACILITIES

In order to insure a cost effective and results oriented advanced materials program, the Oak Ridge National Laboratory was tasked in June of 1982 to organize and conduct an industry/university/government agency assessment of research requirements and on-going/planned ceramics research activities. Based on the results of this assessment, a long-range development plan for establishing an industrial technology base in high temperature ceramic materials is in preparation.

As part of the plan, all research activities will be closely coordinated with complimentary materials research tasks funded by other DOE offices, NASA, DoD, and industry. A joint DOE/NASA technical plan has been developed with DOE focus on ground vehicle applications and NASA focus on aeronautic applications. A common work breakdown structure will be utilized to facilitate coordination. To expedite the rapid transfer of developed technology to industry, the major portion of work under the program will be accomplished in the ceramics industry with technology support from government laboratories and universities.

Since the major thrust of high temperature materials research will be through DOE and NASA programs, in addition to the several professional and intergovernment coordinating committees now in operation, a formal bimonthly joint DOE/NASA program review meeting is held for the purpose of coordinating and planning technical work and reviewing project progress and status. As the program develops, it is planned to organize an industry/university guidance and evaluation board to provide continuing oversite and plan modification recommendations.

In the area of facilities related to materials research, care is being taken to avoid duplication in either government laboratories or university laboratories. Although there are several government laboratories in operation or in the planning stages devoted to materials work, they are for the most part focussed on a specific application or high-cost specialized instrumentation. For instance, NASA is planning an expansion to its Composite Materials Laboratory at Langley - however the work at the laboratory is centered on low-temperature, high strength reinforced resin composites for use in aircraft surface structures, with practically no application to high temperature structural ceramics. DOE is planning a materials laboratory at Lawrence Berkely as part of the Basic Energy Research Program which includes the construction of a large high energy synchrotron - a unique research tool enabling the detection of impurities and defects in a wide range of materials on an atomic scale, and although this instrumentation will have some limited application in planned high temperature ceramics research, it is basically part of the high energy physics program. The High Temperature Materials Laboratory planned at Oak Ridge will focus on basic and applied research specifically centered on new ceramic and alloy materials for high temperature operations, and will include capabilities for microanalysis and processing research as well as basic materials characterization. These capabilities will coordinate with, and will not duplicate, already existing small materials related facilities at Argonne National Laboratory (heat exchanger materials), Los Alamos (highly contaminated environment materials), NASA Lewis Research Center (component test cells, hipping and tribology labs) and the Army Mechanics and Materials Research Center (materials data base and life prediction).

Mr. **Glickman**. All right.

Mr. McCandless, do you have any questions?

Mr. **McCandless**. Yes, thank you, Mr. Chairman.

Mr. Tribble, some of the thoughts and questions that I am going to share with you will evidence my newness on the committee. Forgive that, please. Or that might be overcome by the fact that I spent 28 years in the automobile business, and part of it with "Generous Motors," as I call them. [Laughter.]

I am a little concerned here because I look at the vehicle propulsion R&D, and we talk about gas turbines, which the Chrysler Corp. went through a painful process in trying to develop, unsuccessfully. General Motors has worked on the Stirling engine ever since I can remember, with evidently little success, because it is not anywhere in operation.

You talk here about transportation conservation programs. It would appear to me that if you are going to be living up to the name of your program, that you are trying to find how to propel a vehicle a greater distance on less fuel. Is that essentially where we are headed?

Mr. **Tribble**. Exactly. Well, either on less fuel or on an alternate fuel.

Mr. **McCandless**. All right. Well, if we are talking about vehicle propulsion R&D, it would appear to me that instead of reinventing the wheel, as I perceive it, again with my limited knowledge in these fields that I have discussed, you would be involved in stratified charge, metered injection, variable venturi, carburetor design, those kinds of things which would take the technology that we currently have in the way of a basic engine and improve upon it to the degree that the immediacy, the result in additional miles per gallon, would be more evidenced than to go into such a long and lengthy process as developing a gas turbine program.

Would you share with me your thoughts on where I might be going wrong here in my philosophy?

Mr. **Tribble**. We have a facility at Sandia which is a combustion analysis laboratory. A good bit of work is being done there on just some of the things that you mentioned.

It has been said that, heretofore, the automotive companies did not know exactly where to locate the spark plug, did not know where the particulates were being formed, did not know where the carbon monoxide was being formed, and the facility there enables us to look through a quartz cylinder head with a laser and, through the miracle of laser spectroscopy, determine the constituent products of combustion as the flame propagates from the spark plug throughout the cylinder, as the piston goes down.

So we are doing work in that vein to enable the industry to improve the performance of conventional internal combustion engines. The industry is working with us, taking advantage of that facility.

In the inception of the program for the gas turbine, it was anticipated that if the limitations of known metal alloys with respect to temperature could be exceeded through the use of ceramics, and we could then use the higher difference in temperature: The gas turbine engine would have an inherently higher efficiency than the internal combustion engine.

I have a personal opinion on that that says that that efficiency could certainly be obtained. Unfortunately, gas turbines as we now know them don't have the capability to give good performance with respect to acceleration. A gas turbine is used at its optimum when it can operate at design speeds over long periods of time, and in that way it could very well come into play first in long-haul, over-the-road trucks, so that there could be a spinoff from that.

In regard to the Stirling engine, as the chairman knows, I have some reservations about the ability of the Stirling engine to perform satisfactorily in an automobile. I think it is a fine engine if it is set out on a gas line driving a compressor or in some function where it would be used for a high percentage of the hours in a year. But I don't really feel that it is ever going to have much application to an automobile.

I do not know that I have directly answered your question, but I have attempted to.

Mr. **McCandless**. I would like to just pursue one of those avenues. Let's take the turbine engine, for example.

We have an objective of accomplishing, somewhere down the line—if I understood your comments, you want the size and the design characteristics as well as the performance characteristics in the final version to produce something that is more desirable, burns less fuel, and performs at a satisfactory level in comparison to the internal combustion engine, which is admirable, and it is a worthy goal.

What has the U.S. Government accomplished when they reach that point, whenever it might be, for the amount of dollars spent?

Mr. **Tribble**. If such an engine could be developed and did have the improved efficiency that is the basis of the program, then, of course, we could use a less expensive fuel and in fact get better utilization of the hydrocarbons that we would burn.

Mr. **McCandless**. Now, if we were to take the diesel engine as we now understand it in its application both in passenger and commercial use and spend the same amount of time and effort, wouldn't we be able to reach that objective sooner and have something that would also meet those characteristics that we are seeking?

Mr. **Tribble**. It is difficult to say whether we would get there sooner. There are real problems associated with both. In the diesel engine, in order to get that higher efficiency, we will have to go to the high temperatures; we will probably have to go to solid lubricants—which is something that we do not know how to do now. We can operate centrifugal equipment with air bearings, but I don't know that we could expect to operate reciprocating equipment with air bearings.

So we have some major problems in going up with a diesel into that range of efficiency. There are very definitely problems that have not been solved associated with any of these achieving the objective.

Mr. **McCandless**. The last question, if I may, Mr. Chairman.

Mr. **Glickman**. Sure.

Mr. **McCandless**. We have now two parallel tracks. One is governmental research and the other is private sector. If you look at the General Motors financial statement, how much R&D goes into developing products, much of it is power train oriented. You see, there have to be areas of duplication where we are seeking to, without trying to sound too elementary, both reinvent the wheel.

It would appear to me that there needs to be utilization of those resources for the benefit of the ultimate consumer, certainly to the benefit of the taxpayer, in the research and development section of your and other budgets financed by taxes. Do you coordinate with these other members in the private sector?

Mr. TRIBBLE. Yes, we do, and we stay in touch with them. Of course, if the work that they are doing is of a proprietary nature, they are not going to tell us about it; and we can understand that. But we try, through communication with them, to determine where there may be gaps in the work that is being done or in the knowledge base. We try to direct our efforts toward closing those gaps.

Mr. McCANDLESS. Thank you, Mr. Tribble.

Mr. TRIBBLE. Yes, sir.

Mr. McCANDLESS. Thank you, Mr. Chairman.

Mr. GLICKMAN. Just to follow on that, is it not true that your two basic contracts on your turbine engine are contracts with essentially two of the largest automobile companies in the country, Ford and General Motors?

Mr. TRIBBLE. Yes.

Mr. GLICKMAN. And in fact they are participating, and have been for some time, with you on developing high-temperature engines, ceramics, and related kinds of things.

One of the things, I guess, that concerns me about your going from two to one on the proof-of-concept demonstration of the gas turbine program is that both contractors, both the GM and the Ford groups, have testified that their programs emphasize different aspects of ceramics, and that the most meaningful way to develop and test ceramics is in the engine environment. Therefore, your approach excludes one from that proof-of-concept approach; thus we may not be getting very much in terms of knowledge. We are taking a great risk with all this money we have spent heretofore, and we will not be getting much information out of it.

We visited GM's laboratories and, granted, they do a tremendous amount of research; but not very much of their research is this kind.

Mr. TRIBBLE. I think I am correct, and I hope some of my people here with me will correct me if I am wrong, but I believe that both of our engine contractors are working with at least one of the same ceramic companies on the development of the ceramics for use in the gas turbines. Is that right?

Mr. CHESNES. There is quite a bit of duplication.

Mr. GLICKMAN. But you are still talking about a different concept there, and the idea is how it tests out in an operating engine.

Mr. TRIBBLE. Well, the principal difference between the two engines is that one is a single shaft with one impeller, and the other is two shafts with two impellers. The same problems are inherent in both engines. You have the problem of building the impeller, attaching it to a rotating element, building the combustor, which is a ceramic container for the combustion, so there is a substantial amount of duplication between the two.

I do think that there is some difference between the composition of the ceramics being used by the two engine manufacturers, so that, to the extent that some testing would be done on more than one ceramic material, yes, that is a fact. But the difference is questionable as to how much more we would get for another $12 million.

And let me suggest another thing. I understand they will be here tomorrow.

Mr. **Glickman**. That is right.

Mr. **Tribble**. If we could get adequate cost sharing, we could do both jobs with the same dollars.

Mr. **Glickman**. Have you talked to them about this?

Mr. **Tribble**. We have in the past.

Mr. **Glickman**. In the past meaning not too recently, then?

Mr. **Tribble**. When? Last year?

Mr. **Chesnes**. There is some discussion going on with NASA. There are negotiations, but they are not complete.

Mr. **Glickman**. We will raise that issue tomorrow when we talk to them.

Mr. **Tribble**. Good.

Mr. **Glickman**. I do know that next week Ford and Garrett are apparently going to become more public and announce the ceramic automobile engine and talk about it in greater depth. That is going to be done up here on Capitol Hill, so I think it is useful that we ask them about it.

I guess what concerns me is that the Japanese are apparently spending large sums of money on the development of ceramics in both aircraft and automobile engines. I would hate to see us not do the same thing. I think it has enormous promise.

Let me ask you a question. In your budget, we apparently see a fairly significant drop in the number of civil service personnel in the Office of Vehicle and Engine R&D in fiscal year 1984, from 42 people in fiscal year 1982, 25 people in 1983, and down to 10 people in 1984. Is this adequate to manage a diverse $40 million program?

Mr. **Tribble**. Those numbers, unfortunately, are based on an earlier level of budget. I think we would have to certainly agree that we would have to adjust those numbers, but we have felt that we should wait and see what the budget is going to be.

I have to say that I, personally, am confident that we will have enough people to handle the program at whatever budget level is finally appropriated.

Mr. **Glickman**. On what budget level were these numbers, the 10 civil service personnel based?

Mr. **Tribble**. That is based on about half of what we have proposed.

Mr. **Glickman**. So it is likely that if you would resubmit this today, you would be talking about roughly the same number of people as you had last year, or thereabouts?

Mr. **Tribble**. Probably not quite that many.

Mr. **Glickman**. But double what you proposed, then, 20 or so?

Mr. **Tribble**. On that order.

Mr. **Glickman**. And that again is based upon the numbers that we end up with in the legislation?

Mr. **Tribble**. Yes.

Mr. GLICKMAN. All right. Let me ask you a question on the electric vehicle program. Many in industry feel that the hybrid vehicle is the ultimate answer. Are you going to be doing any work on this in 1984, and what funds have you requested for hybrid vehicles?

Mr. TRIBBLE. I think there is very little that we have asked for in the hybrid. Let me speak to that just a moment. We have the hybrid test vehicle which is now ready for delivery, to be tested. It has a four-stroke cycle, a four cylinder engine.

One of the questions that we debate a good bit is where a hybrid vehicle would fit into the market. It is a very complex engine. As compared to a first car for a family that has only one car, it is difficult to justify, difficult to see how they would be satisfied with this kind of vehicle, when the internal combustion engine has been so well developed and does provide the services that we are all accustomed to.

Then, in a second car, actually, the hybrid vehicle substantially depends on the development of a better battery. And if, in the meantime, we can develop a battery, it is more likely that the second car could be strictly electric.

Now, if we come along with a good battery, if we can develop the battery to the point where it would be serviceable in an electric vehicle, then if there were incentives to go forward with the hybrid, we could pick that up at that time.

But it is difficult to justify spending additional money on a hybrid vehicle when we have one. We have solved some of the problems of feeding into the drive train power from both the battery and the internal combustion engine. That is behind us. I am certain there are other problems that need to be solved, but it appears to us that, in the overall context of the program, it would be better to go ahead and develop a battery; then, if need be, if there were incentive to do so, get on with the hybrid.

Mr. GLICKMAN. For alternate fuels utilization, you have $4 million budgeted for technical problems associated with the use of synthetic fuels, methane, and the alcohols. How does this number relate with last year; is it about the same? And what work will you be doing differently this year than last year?

Mr. TRIBBLE. Last year, I believe we had $1.5 million in that, and this time we have a request for $4 million.

We have, as I mentioned earlier, the facility with which we will acquire and make available to industry various synthetic fuels for testing in engines to see what modification engines have to have in order to burn them.

In the methanol engine, as you know, there are methanol engines on the road now. You can go buy one if you want it. We have a dissociated methanol engine that is working. It is not giving us the best performance in the world now, but it is a catalytically dissociated methanol. The efficiency of that engine is quite a lot higher than direct combustion methanol.

We would like to go further with the development of that engine and work out some of the additional problems that we have with it.

Now, further, I mentioned the work that we will be doing on trying to find a better way of carrying methane on board a vehicle.

Mr. GLICKMAN. What do you mean by a better way? Do you mean how in fact physically to put a CNG or LNG container in a car?

Mr. TRIBBLE. That is right. At the present time, pressures up to 2,400 psig are required for something like a 70-mile range. If we can put that methane into a cylinder that has an absorbant material, we can reduce that pressure for the same range to the order of 300 to 500 psig, which would make it a much safer container to use.

On the other hand, if the development that we think is possible does take place, we could substantially increase the range of the methane-fueled vehicle by going up to, say, 1,000 psig.

Mr. GLICKMAN. I have always felt that CNG, or LNG for that matter, has a potentially significant place in, fleet vehicles for sure, as well as perhaps some nonfleet use. Of course, given the price of natural gas today vis-a-vis the price of petroleum, it is less feasible economically, although that, I suspect, will change as legislation, or whatever happens, brings the price of natural gas into a more accurate reflection of the market.

You know, we did pass a bill in Congress a couple of years ago to try to at least provide a coordinating and an informational role for the Federal Government in the use of natural gas. I am glad to see that you are at least doing something in this regard, because I think there is a potential industry out there; but, there still remain some institutional and technical barriers. Of course, the biggest barrier of all is the same barrier you will find in methanol or in any of the alternative fuels. It is like the chicken and the egg. We've got it, but will people use it; and, where do we get it? It is more than a purely scientific problem.

I just hope the Department exercises its role as a catalyst to encourage the development of this kind of technology and not inhibit it.

I want to thank you for coming. I still want to indicate my concern about the fact that there seems to be a bit of relaxation today in America because of automobile fuel needs and price. I hope that you realize this could change dramatically overnight.

Mr. TRIBBLE. Yes, we certainly do.

Mr. GLICKMAN. If one of the banks falls and one of the countries begins to engage in a revolution and you have military disruption, even though we are only importing 4.5 million barrels a day, that could stop overnight. And if we have economic recovery, for which I know that we are all hoping, those needs can begin to increase rather dramatically.

I do not want to see our technology in automobile development fall, primarily because I also contend this Nation's fabric and structure and our political basis depend upon the ability to be mobile. We are not a country that has very much mass transportation. The automobile is critical.

I would hope that, realizing the problems with deficits we face—we may up your numbers some—you do not fight us in terms of showing a sincere interest in the independence of fuels and engine technology for the transportation sector.

Mr. TRIBBLE. If you do have other places where you feel that it is necessary for us to involve ourselves in other work, we would like very much to have an opportunity to discuss it with you, the committee, or the staff, to work with you in determining those things that have the most technical feasibility. We would certainly like to have that opportunity.

Mr. GLICKMAN. I want to thank you for testifying.

Tomorrow we will hear from representatives of industry: the Garrrett-Ford group; the General Motors group; as well as the Stirling engine people at MTI, who are the prime contracters on these projects.

Tomorrow there will also be a vehicle at the horseshoe displaying the Stirling engine. Next week, the ceramic engine will be available for display as well.

So we look forward to hearing the witnesses tomorrow and working with you as we authorize this part of the Department.

The hearing will be recessed until tomorrow at 2:00.

[Whereupon, at 3:04 p.m., the subcommittee recessed, to reconvene on Thursday, February 24, 1983, at 2:00 p.m.]

[The prepared statement of Mr. Tribble follows:]

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Testimony of

Joseph J. Tribble
Assistant Secretary
Conservation and Renewable Energy

Before the
Subcommittee on Transportation, Aviation & Materials
of the
House Science & Technology Committee

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1984 Authorization for Transportation Programs

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February 23, 1983

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Mr. Chairman, and members of the Subcommittee, I am Joseph J. Tribble, Assistant Secretary for Conservation and Renewable Energy, of the Department of Energy. It is my pleasure to be here today to discuss with you the programs under my supervision through which we attempt to improve the efficiency with which we use energy in the transportation sector.

In my testimony today are several charts that I think you may be interested in and I would like to discuss each one of them very briefly. The first one is a chart of the U.S. imports of oil. This chart shows the importation of oil, both from non-OPEC sources, from total OPEC sources and from Arab OPEC sources from 1960 on through November 1982. We have also obtained the latest total import figures for the four weeks ending February 4, 1983, and have shown them on the chart to indicate the continuing trend. There has of course been a dramatic decline in the importation of oil into the United States since it peaked in 1977. As of February 4, 1983, Gross imports were 4.3 million barrels per day. The relatively low level of imports in this latest figure is the result of many factors. We believe, however, that the two most important factors are the conservation which has taken place, and the reduced economic activity.

The next chart, entitled "Conservation", depicts the growth rate in energy consumption for two periods. The first period is from 1951 through 1973. The second period is from 1973 through 1981. This table indicates a negative growth rate from 1973 through 1981 despite the fact that the Gross National Product did, in fact, grow at an average rate of 2.3% per year during the period of 1973-1981. It is difficult to separate the progress that has been made due to conservation efforts and the reduction in energy consumption because of current economic circumstances. However, we do have a number of figures which help make this distinction. For example, the consumption of energy in the industrial sector has improved by 20.8% per unit of production since the base year of 1972 in the ten most energy intensive industries. Residential energy consumption has been reduced by 15% since 1972 on a per-household basis. For the reduction in energy consumption in the transportation sector I would refer you to the next chart.

The dashed line shows fuel economy standards as provided for in legislation. This is the mandate under which the automotive industry is working. One can see that the new car fuel economy has been ahead of the legislative mandate and the on-road new car fuel economy has tracked the mandated fuel economy quite well. One of the major automobile manufacturers, in its current advertising, boasts of the fact that fuel economy has been doubled since 1973. The lowest graph on this chart shows the average fleet fuel economy. We expect it to continue to improve as the old automobiles presently in the fleet are replaced by those which have a very much better fuel economy.

The next chart shows how this improvement in energy efficiency has come about. There is, of course, a striking correlation between the price of fuel and actual demand. The most important factor is the improvement in automobile miles-per-gallon due to application of existing and new technologies. This evidence indicates that energy producers and consumers have both the ability and the incentive to pursue energy conservation vigorously in response to higher energy prices. The program we have proposed for 1984 is based on our view that the Federal role should be focused on support of longer-term technology base R&D that industry cannot reasonably be expected to support because the economic benefits are too distant and uncertain.

In 1978, when the importation of oil was near its alltime high and there appeared to be limited measures that the United States could take to reduce its dependency on imported energy, the Automotive Propulsion Research and Development Act of 1978 was passed. This legislation is the genesis of most of the transportation program now being conducted by the Office of Conservation and Renewable Energy. I would like to review with you the main components of that program.

The objective of the automotive gas turbine engine program is to provide the automotive industry with proof-of-concepts components for gas turbine engine technology that demonstrate the potential for at least 30% improvement in miles-per-gallon over comparable conventional engines while meeting emissions and noise standards. To date, two industrial teams have designed and built all-metal gas turbines of a size suitable for automotive use.

There remains some test and evaluation work on engine dynomometers of both contractors engine designs of the all-metal engine. During 1983 an assessment will be made of the technical progress and accomplishments of both teams, which will lead to a selection to one contractor. Further progress in this program will depend upon the success of designing and installing ceramic parts for the high temperature section of the engine. Clearly the challenge which is ahead is to design, produce and test ceramic components. We have requested $12 million for FY 1984. With these funds we expect to go forward with the ceramic component development, perhaps for both contractors, but would also support the winning contractor in installing and testing ceramic components in the present all-metal engine which would be used as a test bed. Efficiency of heat engines is limited by the ability of known materials to withstand stress under high temperature. This is also a barrier to higher energy efficiency in many industrial processes. For that reason a High Temperature Materials Laboratory has been proposed to be built at Oak Ridge National Laboratory. The purpose of such a facility is to provide appropriate space and equipment to conduct research designed to provide an understanding of material properties at elevated temperatures. It is intended that the materials to be studied will be directly related to high temperature materials needed for advanced energy systems. It would build on the already substantial expertise which exists at Oak Ridge National Laboratory in high temperature material work. Our request includes $9 million in initial design ($2.8M) and construction funds ($6.2M) for this purpose. Total estimated cost is $20.6 million. Also included is a request for $1.5 million for continued advanced material research in this area.

Another part of our program deals with improving the energy efficiency of heavy duty diesel engines. The approach to this has been to use the waste heat in a way which would contribute to the power generated. It has now been demonstrated that efficiency improvements can be obtained with turbo compounding and also with an Organic Rankine Bottoming Cycle using waste heat. Both of these modifications of the diesel engine add cost and complexity to the engines and will have to wait for adequate economic justification before they are widely utilized. Further improvement in diesel engine operation will depend upon the ability to operate at higher temperatures. Here again, ceramics will play an important part. In addition, it will be necessary to develop new materials for bearings or other innovations which will accomodate the higher temperatures. Our request for $2.6 million in the 1984 budget will enable us to continue work in these areas.

One other aspect of our program is to encourage the use of alternative fuels in current and advanced automotive propulsion systems. Since the inception of this program a great deal of progress has been made in establishing the use of ethanol and methanol primarily as octane enhancers. There are also a number of automobiles burning straight methanol which are in current use. The use of methane has been feasible for many years.

One of the more important projects for the future is to solve any problems that may exist in using fuel from synthetic crude in current or modified engines. We have funded facilities for preparing small quantities of future synfuels for test purposes. An additional project is to look for better means of storing methane on vehicles, such as absorption in porous materials in order to extend the otherwise limited range of the vehicles. Our budget request for FY 1984 is $4 million for activities of this nature. We have also asked for $.5 million to continue the publication of the Gas Mileage Guide.

Still another project that has been ongoing is the adaptation of the Stirling engine for automotive use. The United States built MOD I all-metal engine has been successfully assembled and tested. Further improvements in this engine will depend largely upon the adaptation of new materials and designs to such parts as piston ring seals, regenerators and the combustor. At the Committee's direction attempts were made to find companies within the industry that would be willing to test at their own expense Stirling engines which were furnished to them by DOE. In response to a notice in the Commerce Business Daily the Cummings Engine Company, Inc., has expressed an interest. NASA is continuing to contact other potentially interested companies.

We feel that by the end of FY 1983 sufficient technology development will have been accomplished and adequate test data collected to permit the automotive industry to make a rational assessment of the potential of the Stirling engine for automotive propulsion systems. Consequently, we have requested no funds in FY 1984 for continued development of this engine.

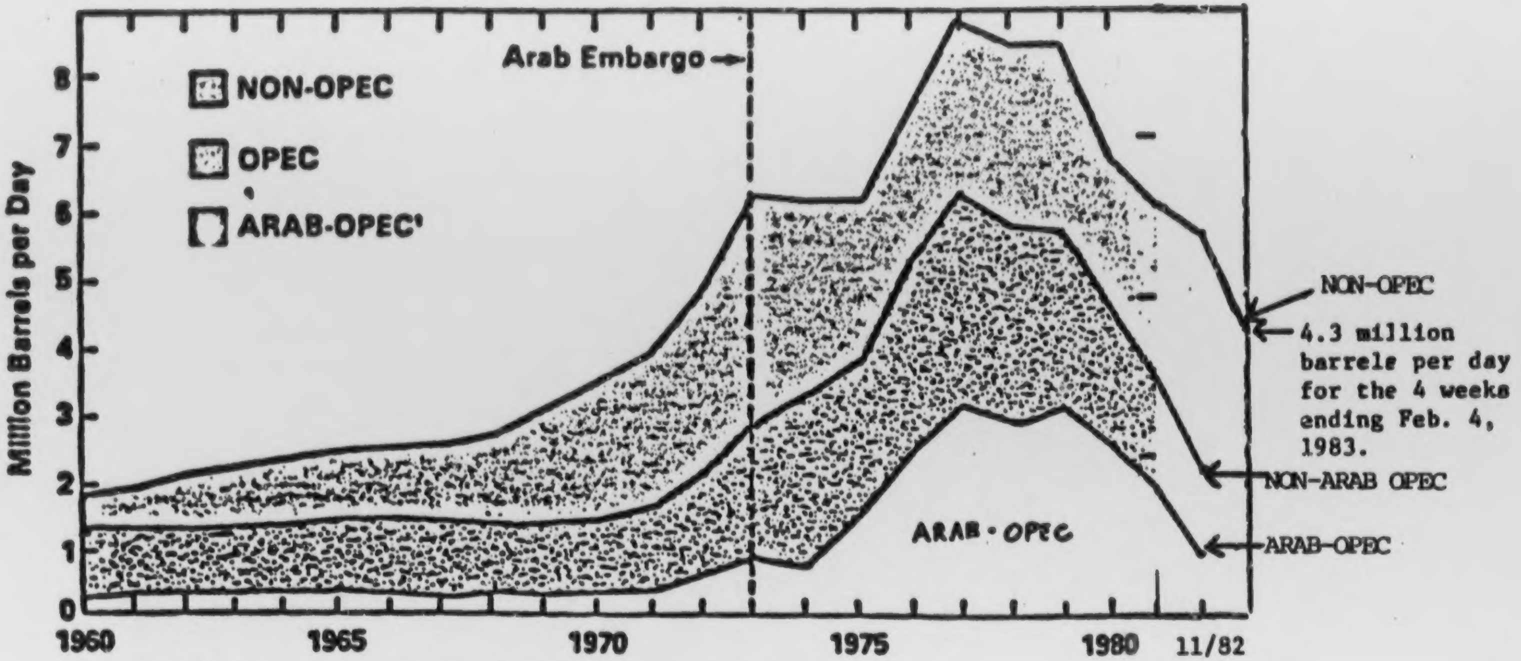
The last part of our program that I would like to discuss is the Electric Vehicle. It has been known for some time now that the successful development of an electrical vehicle depends very much on the ability to build a battery with sufficient energy density, cycle life, power density and lower energy cost. The User Task Force of site operators continues to operate the vehicles in the fleet and report data on their operation. As problems arise they bring these problems to our attention and we make efforts to find ways to solve them. As new developments are produced we assist in their installation and testing. It appears that considerable further progress will have to be made in battery technology before the electrical vehicle will become a practical alternative. Continued battery development is therefore where we would expect to spend the majority of the $9.5 million that has been requested for our FY 1984 budget.

Mr. Chairman, this concludes our formal testimony. We would be pleased to attempt to answer any questions you may have.

FY 1984
TRANSPORTATION CONSERVATION PROGRAMS
($000's)

	FY 1984 Budget Request
Vehicle Propulsion R&D	$16,100
Electric and Hybrid Vehicle R&D	9,500
Transportation Systems Utilization	500
Alternative Fuels Utilization	4,000
Advanced Materials Development	
Operating expenses	1,500
Construction	9,000
	10,500
Program Direction	357
TOTAL	$40,957

U.S. Oil Imports



4.3 million barrels per day for the 4 weeks ending Feb. 4, 1983.

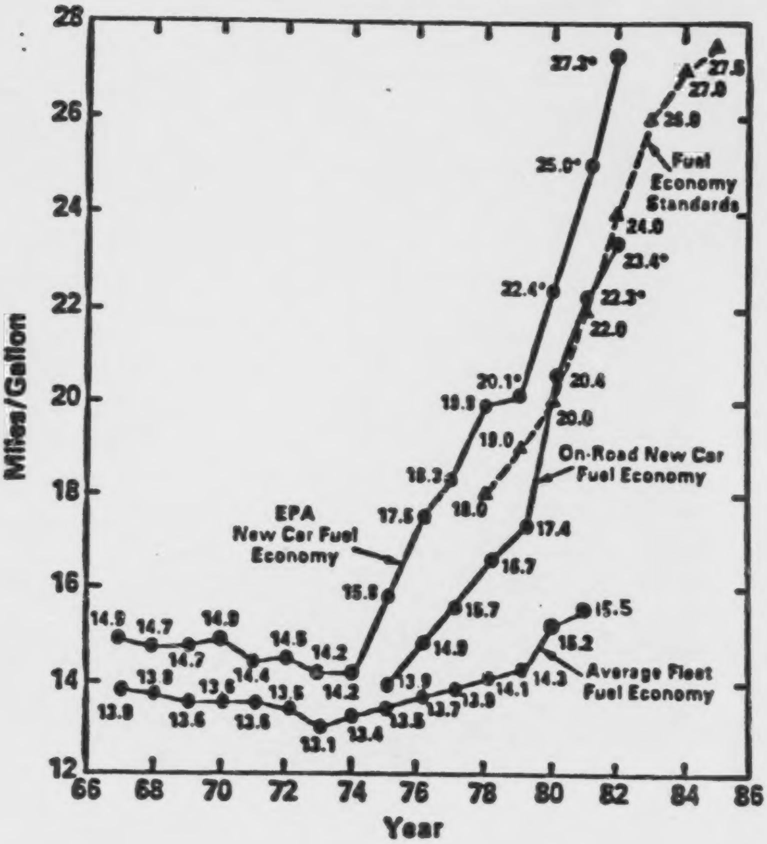
*Saudi Arabia, Qatar, Libya, United Arab Emirates, Algeria, Kuwait

CONSERVATION

	Energy Consumption Growth Rate (%/year) 1951-1973	Energy Consumption Growth Rate (%/year) 1973-1981	1981 Energy Use (Quads)
Residential	4.4	0.6	15.1
Commercial	3.8	0.8	10.6
Industrial	2.8	-1.2	28.9
Transportation	3.1	0.5	19.2
TOTAL	3.4	-0.2	73.8*
GNP Growth (Constant $)	3.6	2.3	

*Excludes approximately two quads of wood derived fuel.

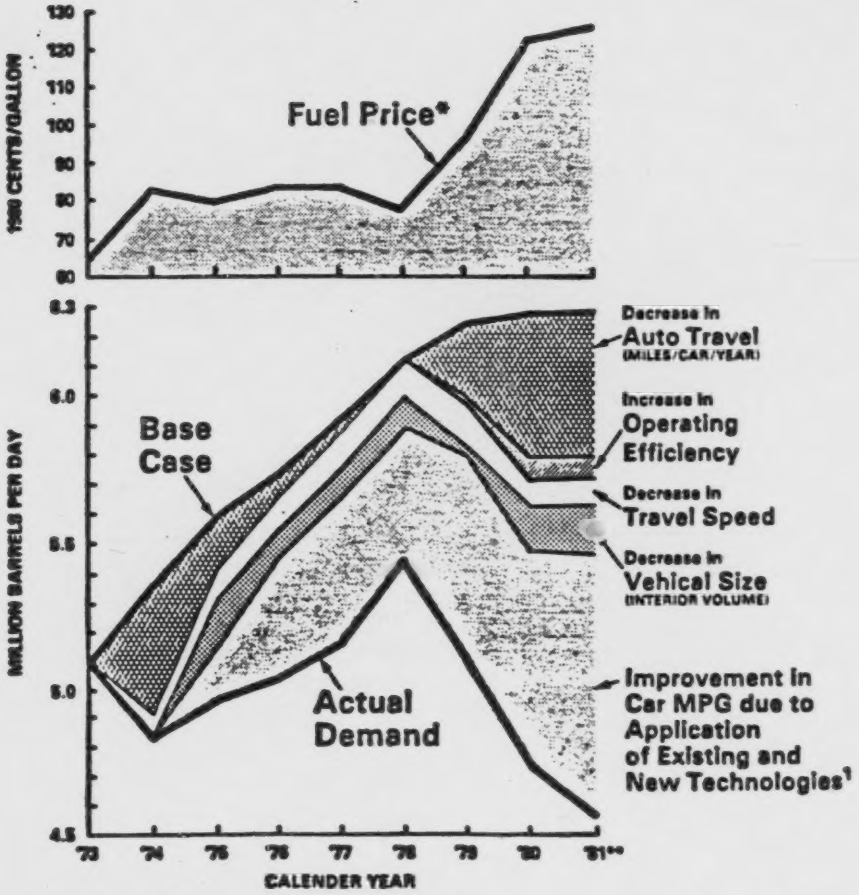
Automobile Fleet Fuel Economy U.S. Passenger Car Fleet



*Based on manufacturers' sales projections

Source: D. Greene; Oak Ridge National Laboratory

Passenger Car Fuel Demand and Price



*The fuel price data represents regular leaded gasoline from 1973 to 1975, and regular unleaded gasoline from 1976 to 1981.

**Through mid-1981.

[1] Includes vehicle weight reduction, exterior size reduction, material substitution, front wheel drive installation, decreased aerodynamic drag, improved accessory efficiency, and decreased rolling resistances.

Source: C.Difiglio, and B.McNutt, Passenger car Fuel Demand Reduction—An Analysis of the Causes and Implications, DOE Office of Policy, Planning, and Analysis.

1984 DOE AUTHORIZATION

THURSDAY, FEBRUARY 24, 1983

House of Representatives,
Committee on Science and Technology,
Subcommittee on Transportation,
Aviation and Materials,
Washington, D.C.

The subcommittee met, pursuant to notice, at 2:06 p.m., in room 2325, Rayburn House Office Building, Hon. Dan Glickman (chairman of the subcommittee) presiding.

Present: Representatives Glickman, Harkin, Carney, and McCandless.

Mr. Glickman. Why don't we go ahead and start? Mr. Carney was here, and he ought to be right back.

Today we will conclude the subcommittee's review of our part of the Department of Energy's fiscal year 1984 budget request. Yesterday we heard from the Department. Today we will follow with testimony from the three principal industrial contractors in the heat engine program.

These projects were born in legislation that originally came from this committee. Since then, they have made excellent progress toward accomplishment of the goals identified in the act.

Yet, despite this and what I believe to be their obvious long-term merit, the administration has consistently tried to undermine them. This year, for example, they are again proposing to terminate the Stirling engine project, in spite of previous congressional intent to complete it.

For this reason, we have invited each of the major participants in the heat engine program to give us a status report and an assessment of their project's outlook for eventual commercialization.

I might point out that even though I, as chairman of this subcommittee the last 2 years, have supported these projects and expect that I will continue to do so, I do not operate under the theory that just because we have done them in the past means we have to continue them. I would expect that in your testimony today you will give as great a rationale for the progress that has been made to date and how long you expect the relationship between the Government and the private sector to continue. I think that in order to insure that we fulfill our oversight mandate as well as our authorization mandate, we need to do that. Too often we just tend to authorize just because it has been authorized before. At the same time I realize many of these are long-term projects.

Your testimony will be included in the record in its entirety, so feel free to summarize it. I would hope that you could try to emphasize those things that I mentioned.

Our first witnesses today are Dr. Bob Lawrence, director for technical development; Mr. Noel Nightingale, program manager, Automotive Stirling Engine Development Program; and Mr. Bruce Goldwater, general manager of the Stirling Engine Systems Division of Mechanical Technology, Inc.

It is a pleasure to have you all here. Why don't you begin.

STATEMENT OF NOEL NIGHTINGALE, PROGRAM MANAGER, AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM, ACCOMPANIED BY DR. LLOYD R. LAWRENCE, JR., DIRECTOR FOR TECHNICAL DEVELOPMENT; AND BRUCE GOLDWATER, GENERAL MANAGER, STIRLING ENGINE SYSTEMS DIVISION, MECHANICAL TECHNOLOGY, INC.

Mr. NIGHTINGALE. Thank you, Mr. Chairman.

I have submitted a written testimony on the Stirling engine program, and I ask that that be entered into the record. However, for your convenience, I have also submitted a summary brief, which is also I believe on your desk.

Mr. GLICKMAN. Fine.

Mr. NIGHTINGALE. I have viewgraphs of that summary. I think this will be the highlight of my oral presentation today to you.

Mr. GLICKMAN. OK.

Mr. NIGHTINGALE. One of the areas which was mentioned last year in the testimony was the stumbling block associated with industry acceptance of the Stirling engine technology. I thought that I would address this issue first today.

Over the past 12 months we have had two automotive companies which have shown interest and are, in fact, evaluating their resources to become actively involved in the evolution of the Stirling engine program, either as an engine system or in a vehicle itself. In fact, MTI was visited by the two automotive companies to review the advances made in the Stirling engine technology under the ASE program. The purpose was, of course, to get a feeling for where the Mod I was and the future Mod II testing.

In early December 1982, NASA issued in the Commerce Business Daily a notice advertising that they would be making two Mod I engines available to industry for test and evaluation at their site. Since that letter was released, the Cummins Engine Co. has, in writing, committed to NASA to receive one of those engines in late 1983 for test and evaluation at their facility.

I might add—and this is not in the testimony because I just received it today—that we also received a letter from General Motors this morning, or yesterday afternoon, and they have committed to test one of the Mod I engines in a vehicle as well.

There was also something else on this issue. The Cummins Engine Co. has also shown an interest with MTI to use the Stirling engine as a bottoming cycle in their adiabatic diesel program for the U.S. Army. That is an example of how some of this technology is now being transferred into other applications.

I would like to move on now, then, to perhaps a few summary items of the accomplishments made during fiscal year 1982.

In the engine area, we tested another 1,300 hours. Last year we reported 500, and now we have tested 1,300 hours, bringing the total number of engine hours on the four Mod I's to 1,800.

As a demonstration of the technology transfer, we also have built one of the Mod I engines here in the United States. We used a U.S. vendor base, which was about 30 vendors, and we assembled and successfully tested that engine this year. The number of hours on that engine when we closed was about 235 hours.

One of the major program milestones which was established years ago, at the beginning of this program, was to have a Mod I characterized in its transient mod by the end of September 1982. We accomplished that, and that leads me into the next viewgraph, which is data from that transient test program.

I think I would like to highlight that. We ran numerous tests. I have summarized here three of them and given you an average at the bottom.

You will notice that the hydrocarbons and carbon monoxide levels are already well below the program goals, which were 0.4 gram per mile and 3.4 grams per mile respectively.

The NO_x level was 0.9, and, of course, the program goal was 0.4. We will be pursuing that goal, and that will be met in the Mod II program.

The mileages here, you can see for the urban and the highway and the combined, met with our projections. I think that the key point I wanted to emphasize here was the fact that we used the same projection methodology for our Mod II engine.

Another accomplishment made in the program was to reduce the manufacturing cost in the Mod II engine system. A couple years ago we had our engine costed by a private concern, Pioneer Manufacturing in Detroit, and they came back with an assessment that the Mod II engine design was not competitive with diesel and IC. Over the past 2 years we have been incorporating several cost-reduction ideas into that engine, and the next graph shows basically the growth path in reducing the manufacturing cost of the Stirling engine. It shows the discrete improvement in manufacturing costs of the Mod II relative to the experimental engine, Mod I, or the currently updated Mod I, which is just going on test today.

We would like to emphasize the following point: To answer one of your questions, Mr. Chairman, how long the program should go on, we feel that we have to demonstrate in hardware the Mod II engine for industry with this type of a manufacturing cost, and that the Mod I would not suffice.

Another further accomplishment in the program year was the upgraded design of the Mod I. We felt that the Mod I had missed its goals in some areas and needed improvement, and we needed to take some of the technologies that we knew had to be incorporated in the Mod II engine system and we incorporated them into the Mod I. We call it the upgraded Mod I engine.

That engine is on test today at MTI and is on test in Sweden as well.

Some of the questions that were raised in the testimony last year was the criticism of Stirling engines for high specific weight and the use of strategic materials. We have been able to reduce the specific weight. Efficiency has been increased. The fuel economy has been increased, and we have reduced the amount of strategic materials in the Mod I.

I would like to show by means of the next four graphs the growth path through the program on those specific parameters.

Addressing first specific weight, the Mod I and the upgraded Mod I specific weights are above the IC and diesel, but through the weight-reduction items that we instilled in the Mod II design, you can see that by 1985 the Mod II engine will be competitive with diesel and IC on a specific weight basis.

I think this graph points out the improvements and the growth that have occurred over the process of the ASE program.

On the next graph is a graphical representation of the improvement in the peak efficiency of the engine. The Mod I and the upgraded Mod I showed discrete improvements over the base-line engine and the Mod II also will show an improvement in peak efficiency.

However, efficiency alone is not enough in terms of an automotive application. It really has to be converted into miles per gallon. That is reflected on the next graph.

This graph shows, relative to the IC mileage, that the Mod I was about even with the IC mileage and that the upgraded Mod I with some of the Mod II technologies incorporated in it will give about an 18-percent improvement. That is on a growth path toward the title III goal of 30 percent better than the IC engine. Right now we are predicting that the Mod II would be considerably better than that, up in the range of about 50 percent better than the IC.

The criticism of Stirling engines using strategic materials—I have pulled out two of those elements for your review—cobalt and chromium.

In the case of cobalt, we have incorporated in the upgraded Mod I design, materials which do not contain any cobalt at all, and that will also hold true for the Mod II program.

In the case of chromium, you cannot totally eliminate chromium because it is used in stainless steel. However, you can see the growth path in this next viewgraph of how we have been able to reduce the amount of chromium in Stirling engines, and, in fact, the Mod II through its use of ceramics in some critical heat exchangers will bring the amount of chromium down on a pounds-per-horsepower basis comparable to the IC or diesel.

In addressing what we propose for next year, I have another viewgraph which summarizes basically what we would outline as a program.

We would initiate the final design of the Mod II engine system. We have already initiated a preliminary design which we will finish in 1983. We would initiate the long-term procurement of the hardware for the Mod II engine. We would continue to advance the technologies which would continue this growth path that I have shown in the earlier viewgraphs for lowering the manufacturing costs, reducing the specific weight, reducing the size, increasing the efficiency, lowering the NO_x emission specifically, and increasing the fuel economy.

One of the concerns of Stirling engines is the sealing mechanism, and we have advanced sealing development going on in the program. We will continue that effort to get the reliability and durability to the point where industry would find it acceptable.

We also would plan, of course, to continue to support the industry test program, which I referred to in my opening remarks.

In conclusion, Mr. Chairman, I feel that the ASE program has advanced the Stirling engine technology to a level where the U.S. industry is interested. This interest has been shown through their visits and questioning of the program, but this interest is in the Mod II engine hardware.

It is interesting to note that we have been in this program now for 4 years, and only when we had the Mod I engine in hardware form was the industry interested. We believe that we have to take the Mod II to a hardware basis before that interest would be culminated.

I think that this interest, therefore, would wane if the program did not develop the Mod II engine system.

I must say that in dealing with the industry there is evidence that their resources are very tight. To expect that they would pursue this type of advanced development in today's current situation I think is unlikely—we have not seen any evidence of that capability.

During fiscal year 1984, also, we would have developed the technologies required for the Mod II where we could build the engine and test it.

As I mentioned in my opening remarks, there are other technology bases for which the Stirling engine technology coming out of the ASE program is being applied; for example, the interest of the Cummins Engine Co. in using it in a bottoming cycle.

I must say that we were also contacted by another company in the Midwest that is looking at Stirling engines for irrigation in the agricultural field.

There is no doubt—and I do address this in a little bit more detail in the written testimony—that there is increased attention and support by foreign governments and companies. This we know is going on in Japan and in Germany.

I think, therefore, that the ASE program is a successful example of the type of program that the Federal Government should support to address the major national needs, and that the original goals established in title III are still valid and in the public's interest.

Just to extend that thought refer to my last view graph where it shows the national benefits that we feel would come out of a successful ASE program:

I think that the new technology would provide new jobs in American products across a broad base; that this type of technology can be expanded, as we are already starting to see early examples of, in other applications, perhaps heat pumps, electrical generation.

We always have the security of a multifuel engine system which, in the case of petroleum displacement, we can always fall back on.

Certainly pollution of the environment can never be ignored. The NO_x levels, the CO and hydrocarbon levels, must always be addressed. The Stirling engine, in fact, as you probably know, when installed in a vehicle, does not require a catalytic converter.

The conservation issue of 30 percent better fuel economy and 50 percent better fuel economy I think offers a viable heat engine system.

Of course, the noise issue—the noise I think mainly in the densely populated cities, the Stirling engine would show a benefit there.

Again, I say that when installed on a vehicle, I think we are all aware that the Stirling engine does not require a muffier.

That, more or less, concludes my remarks, Mr. Chairman.

I might just say that we do have our Mod I installed in a transient test bed, as we like to call it, or a vehicle parked outside the building. It is certainly open to you and members of the committee.

I would be quite willing to address any questions you might have.

Mr. GLICKMAN. Thank you, Mr. Nightingale. I do intend, if we finish in time, to go outside and look at it.

Let me ask you this question: If the program is terminated at the end of this fiscal year, as the administration has proposed, where will you be with respect to meeting the goals identified in the basic law, the Automobile Propulsion Act?

Mr. NIGHTINGALE. I think that some of the graphs I showed in my oral presentation would address that.

To basically summarize that, I would say that we would have a semideveloped Mod I engine in an upgraded version, that we would be partway along the Mod II development, and that it would be at a stage at which industry I do not think would be interested in picking it up.

The current level of parameters such as specific weight, mileage, et cetera, would not be of interest to the industry at that point.

Mr. GLICKMAN. What do you estimate the cost to be to complete Mod II?

Mr. NIGHTINGALE. This was addressed last year as well. We are consistently saying that from the MTI point of view, we feel that 3 more years are needed: 1984, 1985, and 1986.

It would require, relative to the contract that we have now for $89 million, $12 million more to complete the Mod II program.

If you remember, our contract today exists through to 1984 and was at $89 million. We feel that in order to develop the Mod II and to deliver it by the end of 1986 would require $12 million more on top of that $89 million.

Mr. GLICKMAN. I'm sorry. $12 million more on top of——

Mr. NIGHTINGALE. On top of the $89 million.

Currently, today we have spent about $55 million to $60 million.

Mr. GLICKMAN. I am trying to figure out how many more dollars in the aggregate you will need after fiscal year 1983.

Mr. NIGHTINGALE. About $40 million.

Mr. GLICKMAN. $40 million?

Mr. NIGHTINGALE. Yes.

Mr. GLICKMAN. Again, how much in fiscal 1984 do you think you would need?

Mr. NIGHTINGALE. We are proposing in the written testimony, in fact, $16 million appropriation. We see that probably $13 million would be awarded to the MTI contract out of that appropriated level.

The reason for the $13 million is that, as I said, the Mod II initial design would start, and we would be ordering the long-lead hardware items.

Mr. GLICKMAN. Is there any chance for any form of cost-sharing or other nongovernmental commitment that has not otherwise been in the program?

Mr. NIGHTINGALE. I think I would have to address the conversations we have had with industry up to this point. Of course, the discussions have been very minor and short, but industry does have a difficult time finding the amount of resources to even test an engine in a cell. When you think of the resources that some of these companies have and they are having difficulty breaking loose one test cell to test one engine, I think that I would have to say that we have not seen any indication that they would be willing to costshare at this point in time.

Mr. GLICKMAN. What is the outlook for some sort of commercialization after Mod II is completed?

Mr. NIGHTINGALE. I think that the goals that we have established on the graphs that I showed for the Mod II as a developed system would be a system that could go into a preproduction phase.

I would have to say that the interest so far generated in industry is not necessarily so much on the Mod I but on what the Mod II will offer.

Mr. GLICKMAN. Now, again, tell me, what is your goal on fuel economy and emissions when Mod II is completed? Where are you reasonably looking?

Mr. NIGHTINGALE. At least 30 percent better than an IC engine——

Mr. GLICKMAN. Which would be how much per gallon on petroleum-based products?

Mr. NIGHTINGALE. Of course, you get caught up in what size vehicle. In the type of vehicle we are talking about, we are looking at an "X" body, a 3,000-pound vehicle, about 41 miles per gallon combined.

Mr. GLICKMAN. Combined?

Mr. NIGHTINGALE. Yes.

Mr. GLICKMAN. Then how about emissions?

Mr. NIGHTINGALE. Emissions would meet the 1985 Federal standards. Do you want the specific numbers?

Mr. GLICKMAN. OK.

Mr. NIGHTINGALE. Specifically, the NO_x level I think is the one of concern——

Mr. GLICKMAN. Yes.

Mr. NIGHTINGALE. And that is 0.4 grams per mile.

Mr. GLICKMAN. Right now your Mod I engine does not meet that?

Mr. NIGHTINGALE. No. It is slightly above it, yes.

Mr. GLICKMAN. Regarding fuel economy, are you talking about a Mod II engine at the end of 1985 meeting the 1985 fuel economy standards?

Mr. NIGHTINGALE. Yes.

Mr. GLICKMAN. Mr. Carney, do you have any questions?

Mr. CARNEY. Yes.

You said at the completion of Mod II, when the chairman asked about production, you used the term, "it would be ready for preproduction."

Mr. **Nightingale**. Yes.

Mr. **Carney**. What does that mean?

Mr. **Nightingale**. We are a research and development house. I think the one thing that we do lack is a strong industry input into the engine design. I am sure that General Motors or Ford or any of the large industry companies would have their own way of making the design more adaptable to their manufacturing process. I think that that would call for a pre-production-type mode before they would go into full production.

Mr. **Carney**. How much flexibility is there in changing the configuration of an engine of this nature?

Mr. **Nightingale**. It is considerable. It has pistons. It has crankshafts. It has cases. It is very similar to an IC engine in many ways.

We as a research and development house try to stay very close to the manufacturing advances in the field, but I am sure that they could incorporate their own ideas.

Mr. **Carney**. If the major automobile companies are interested in it—and the last time I talked to all three of them they specifically told me they would never put it in their automobile line—if that has changed, why don't they make some type of financial commitment to the program?

Mr. **Nightingale**. I think at the stage, as the graphs show, we have accomplished, I think, a great deal in taking the Stirling engine technology to the level it is today, but I think it is still long term.

Mr. **Carney**. If you have not accomplished the commitment to put it in a production model, if you have the best mousetrap in the world and the manufacturers who use the mousetrap say they do not want to use it, you have not accomplished anything in my view. That is the problem that I see.

I continually hear from the guy who is going to use your mousetrap that he is not going to use it. I question why we keep throwing money into the R&D under those circumstances.

Mr. **Nightingale**. I think that——

Dr. **Lawrence**. May I try to respond to this?

Mr. **Nightingale**. Sure, go ahead.

Dr. **Lawrence**. Mr. Carney, I think if we look historically at the relationship between this program and the automotive industry, 2 years ago I think the industry was actively negative on this program.

Mr. **Carney**. A year ago.

Dr. **Lawrence**. Maybe even a year ago. However, today we have been visited by General Motors in August of this year.

Mr. **Carney**. Did they come with their checkbooks?

Mr. **Glickman**. They never come with their checkbooks.

Dr. **Lawrence**. Let me review what I think your concern is. Your concern is, how do we insure that the automotive industry picks this up and we are not wasting the taxpayers' dollars in this investment.

There is a time period needed going from an engine which is a prototype form or semideveloped form to an engine that is applicable to an automotive application. There are a lot of technologies that need development, and it takes time, it takes skills, it takes money.

As an industry that manufactures—MTI is half manufacturing in quality control equipment and turbo machinery. I think that the automotive industry—I certainly cannot speak for them, but any industry looks at how much money they have to invest and when they are going to get it back. Today it is a tighter investment scenario than ever before.

I think what we are looking at is the time period from where we are right now to the point where you could logically say, OK, we can put this engine in production and make it a commercial engine. That time period is too long in the automotive industry's investment scenario to make that investment now.

Mr. Carney. I think the goals of fuel economy and the goals of clean air or emission goals, whichever is a better way of saying it, are not any greater than the IC goals that the automobile industry has now. Why would they go and get involved in retooling and everything else?

Dr. Lawrence. I think, Mr. Carney, that the technology itself, the Stirling technology, the original reasons for going into it were that these particular goals can be met more easily with that than they could with an IC engine.

For one, instead of explosive burning, which is by its nature inefficient, you have a flame in this vehicle so that you do not get the same kinds of pollutant-combustion products.

In terms of its efficiency, the Stirling cycle is inherently more efficient than the auto cycle which is in your internal combustion engine. Therefore, its potential as an engine, just on an engine-for-engine basis, giving you considerably better gas mileage, is there in the Stirling. That is why it was picked. That is why the JPL study chose it.

Mr. Carney. Let me ask you this: Your goal of 41 miles per gallon in an automobile 3,000 pounds on an "X" frame, the IC could reach that goal without any problem by the time you are finished doing your prototype.

Dr. Lawrence. I think on an engine-for-engine switch, if you did the other kinds of things that the industry is doing today in terms of downsizing and aerodynamic design, and what have you, when you got all finished and you had an IC engine in that car, on an engine-for-engine switch—don't change anything else in the car; take that engine out and put in the Stirling engine—you would find that the automobile had improved in its gas mileage by 30 to 50 percent. That is just the nature of the Stirling technology. That is why it is being pursued.

Mr. Carney. I would think that 41 miles per gallon on a 3,000-pound car is a goal that is obtainable at present with the IC engines. If I were a manufacturer of an automobile and that was the goal, and I am already tooled and I am already in this business, and have been for a long, long time, why would I change my engine type?

The only incentive I see for their coming to you is, sure, it is not costing them anything. Maybe there will be a major breakthrough. However, other than that, they keep coming to me and telling me they are not going to put that engine in their car. Those were the three major automobile manufacturers that I went out and sought on the last go-round on the engine. That was the comeback I got from it. Therefore, I am just wondering why we keep doing it if there is not going to be an application for it.

Dr. LAWRENCE. I guess, Mr. Carney, I would encourage you to talk to them again and see if, in fact, that attitude has changed, or exactly what they are looking for in terms of when they might be able to pick it up themselves.

Mr. CARNEY. Perhaps their attitude has changed. I have not had an opportunity to talk to them this year, but an attitude of a year ago—I find it hard to believe that it would have changed, but I will be glad to go back and speak to them as well.

Dr. LAWRENCE. Thank you, sir.

Mr. CARNEY. I do not have any further questions.

Mr. GLICKMAN. Mr. McCandless?

Mr. MCCANDLESS. Thank you, Mr. Chairman.

I have a little problem with the whole program, so I will be coming from that direction, but hopefully politely.

Stirling engines have been around for many years, and each time they come up for modernization they have been dropped because the concept is not acceptable when related to the other types of engines; that is, diesel and internal combustion.

Here we are spending taxpayers' money to develop something that industry in previous years has discarded as being inefficient or too costly to build or to weighty, whatever.

Let's try a scenario for purposes of our discussion and say that your second model does have characteristics which are favorable for installation in mobile sources and that your preproduction model establishes that the characteristics, in fact, can be automotive oriented.

Now it would appear to me that we have a price list on a given automobile somewhere, and that here we have the internal combustion engine and over here we have the Stirling engine, which will sell for "X" number of dollars more, as the alternate engine option in this vehicle, as exampled by current gasoline-diesel options in the same automobile.

What would be your estimate as to the additional cost at that level of this finished product in the hands of one of the automotive manufacturers?

Mr. NIGHTINGALE. At best, I would estimate that it would be the same as the diesel, and our goal is to bring it down to being equal to the IC.

Mr. MCCANDLESS. We currently have in most of the vehicles that offer these options as standard somewhere in the neighborhood of $600 to $900 differential between the cost of the internal combustion engine and the diesel engine in that same configuration, depending upon where you are going to go with your internal combustion engine. If you are going to pay another 55 and get some more cubic inches, then the differential becomes smaller.

Therefore, if you took an automobile with an average gasoline consumption of somewhere in the neighborhood of 17 miles per gallon, and the diesel had an option of 22 miles per gallon by practical experience, then we are talking about a savings over a 50,000-mile period of somewhere in the neighborhood of a thousand dollars by last year's cost of diesel fuel and gasoline.

The individual, then, is going to have to drive the car longer. He is going to have to be more successful in the field of nonfailure on the optional engine, in order to justify the initial cost of that engine option.

In many cases the person who thought he or she was going to save money by having a diesel option and was willing to accept characteristics for that savings, it turned out in most cases that the cost differential between the two did not prove in the long run to be a cost-effective decision in purchasing the optional engine.

Placing the Stirling engine in this kind of a situation, it would appear to me that until such time as we have a great deal more experience actually on line, the Stirling engine then is currently part of our experience, that we are going to find ourselves in a similar situation where we are going to have the famous field testing by the man who purchases it but does not seem to be able to be duplicated on any test track. We are going to find another kind of diesel-versus-gasoline option.

I do not know if you want to comment on this or not, but that is where I have my problems with the program.

Mr. NIGHTINGALE. Certainly, Mr. McCandless.

I think that what we have to do in the case of Stirling engine—it is certainly a difficult question to answer, to say that 30 percent better mileage, just looking at fuel economy, would justify a retooling and going to a whole new engine system. That seems to be a very difficult question with which to deal.

However, I think you have to look at the Stirling engine as a total package. One thing that is not going to go away, I do not think, is the pollutant issue. Certainly, when I have driven behind a diesel car and see the black specks on my windshield, that issue is still here and still has to be dealt with.

With regard to the noise issue, we were contacted 4 or 5 years ago by a Japanese company that wanted to use Stirling engines in construction machinery in the downtown areas because of the loud noise that comes out of front-end loaders and bulldozers, just the noise level.

I think if you looked at the total engine system, that may come across as a viable option. Fuel economy by itself may not sell.

That is why, when we address the goals in this program, fuel economy was one of them but it was not the single most one. It was coupled in with these other issues. We are trying to address them on a broad front.

Mr. MCCANDLESS. On a component basis, when you are using new technology and new materials, as your paper outlined, there is certainly going to be a failure rate in excess of a tried-and-proven engine that has gone through that at some point in its history.

How do you see the manufacturers of these cars who would put in this engine going about the process of installing this, when we have a whole new product that still really needs to have a shakedown of a major magnitude before the industry is willing to accept the warranty liability that would be coming with it?

Mr. NIGHTINGALE. That is a very difficult question, too. However, I would have to point to the similarities, I think, between the Stirling engine and the diesel or the IC engine, in that we have crankshafts, we have bearings, we draw upon all of that expertise.

I think the mechanism that would be applied here would be directed at the single or small number, finite number, of items or components which are strictly Stirling components.

We still have auxiliaries. We still have alternators. We still have pulleys and belts. We still have, as I said, crankshafts, pistons, and piston rods. Those are in the infrastructure today.

The way the companies would address this would be to go after the quality control of the Stirling engine parts themselves, and there are not that many that would require that kind of scrutiny. I think that is the way they would be able to get to a point of giving some type of warranty on this system.

Mr. MCCANDLESS. Let's take an example, then. Mazda came out with a rotary engine. It was the new kid on the block, and everybody thought it was a great idea. It had certain characteristics. However, the wipers would not last beyond 40,000 miles, and there were possibly some other defects, but that was the major factor—being able to create something that would withstand what the wiper was required to do within the engine. I believe that Mazda has pretty well given up on that idea and gone back to the conventional engine.

Yet, there is a very simple engine with a very simple problem that to date appears to have defied technical solving, but you are saying to me, well, the Stirling engine would not necessarily have those kinds of problems. I do not quite relate because of the experience that Mazda has had in its inability to find whatever the commodity is that is necessary in the way of an ingredient to make those wipers.

Mr. NIGHTINGALE. I think the time spent on the development of an engine is directed at bringing out those problems. I think that is probably the basis for my earlier statement that it would enter a preproduction phase. A program such as this is really hardware limited. Even though we advertise 1,800 hours on the Mod I engine, I think a manufacturer is talking 30,000 hours on engines, 50 cars or fleets out there telling them these types of stories.

If the development of the system is systematically approached, the Stirling engine probably can come out of it in a better state than the others.

Mr. MCCANDLESS. Because, to use my colleague's terminology, you have a better mousetrap?

Mr. NIGHTINGALE. Yes.

Mr. MCCANDLESS. Anything is possible certainly.

The Japanese have been virtually genuises in solving certain kinds of problems that deal with mechanical apparatuses. This one has defied their solution. I keep drawing on this as a reference point in listening to the testimony and reading the documentation here about what a great configuration this is and how it is going to solve many problems. I am saying if it is that kind of an engine, where has it been? If you can solve those kinds of problems, why haven't people been able to solve the problems on other types of engines?

Mr. NIGHTINGALE. I guess I would key off of your point that the Japanese are working on the program. We know that they have a program in which they have $40 million of material dollars. They are looking toward the timeframe of now to 1988. Forty million dollars of material, when you add in labor, and so forth, is around a $200 million program. There must be something there.

I cannot give you a guarantee that the Stirling engine is the solution to all, but certainly the improvements that we have been able to accomplish in this program from the technologies of just 10 years ago when General Motors—or 15 years ago—when General Motors dropped out or 5 years ago when Ford dropped out, give encouragement.

When they visited us, they were amazed at the quantum steps made in the technology. I think if we pursue it, we will have a better mousetrap.

Mr. MCCANDLESS. Thank you, Mr. Nightingale.

Mr. GLICKMAN. Let me ask you a couple of questions.

One of the things that has intrigued me about all of the heat engines is the ability to burn fuel other than petroleum, and you did not mention that in your statement. I think the impression was left that maybe we do not have any fuel economy which is better than an internal combustion engine and 3,000 pounds. Don't you have to consider the fact that you can burn anything in the engine?

Mr. NIGHTINGALE. Yes. The multifuel capability I downplayed today, simply because we had highlighted it a year ago, Mr. Chairman. We have tested one of the engines on five experimental fuels, and we did not have to change anything in the engine. In fact, the vehicle out there today has three gasoline tanks. When you drive it, if you choose to, you can press a button and change from diesel to unleaded to kerosene, and you do not notice any difference in the performance of the engine.

Therefore, the multifuel capability is always there, and it has always been a design requirement for us.

Mr. GLICKMAN. The other thing is that you talked about the application in things such as irrigation. Are we looking at something that may actually have more application in a nonautomotive use than in an automotive use?

Mr. NIGHTINGALE. Yes. To answer you directly, yes. I think that this technology, as is the case with diesel and the application of diesel in other areas—I do not think it is restricted to the automotive application. I would have to say that the automotive application is, indeed, the most difficult because of the constraints put on it on specific weights and size and packaging.

If we talk about generator sets, we do not have to care about weight. We can make things thicker and out of cheaper materials.

I think the automotive is one, and maybe one of the leading applications.

Mr. GLICKMAN. Do you have a final question, Mr. Carney?

Mr. CARNEY. Yes. I would like to make a comment on the fuels and I would like to make a comment to follow up Mr. McCandless' questions, if I may.

You say you burn five different types of fuels in it. Three of them, if I am not mistaken, are gasoline, diesel, and kerosene.

Mr. **Nightingale**. Yes.

Mr. **Carney**. Is that correct? They are all derivatives from the same oil base; they are just refined to different levels. In today's economy and today's market, they are all comparatively priced.

What are the other two?

Mr. **Nightingale**. The other two are an experimentally derived fuel which was a very thick, heavy type of diesel. Another one was, again, a heavy oil, diesel type of fuel.

Dr. **Lawrence**. Both synthetics.

Mr. **Carney**. All five were derivatives of oil?

Dr. **Lawrence**. One was the shale oil derived——

Mr. **Nightingale**. Yes, shale oil derived, right.

Mr. **Glickman**. What about alcohol?

Mr. **Nightingale**. We have never tested the alcohols except experimentally in the car. I think that when you start to talk about alternative fuels, the problem is not with the engine but with the handling system of the fuel. We have, in fact, received fuels that we could not handle, that you could not ask our technicians to handle. If we put them into the fuel tank and put them into the fuel line, it would eat away the "O" rings. However, the engine really does not care. Once that fuel is lit, the engine really does not care.

I think the concern with the multiple fuel is the handling system. If we can get it to the engine, it will take it.

Mr. **Carney**. The other question is a followup to my colleague from California. He was talking about acceptance and the public view of the gamble these would, no doubt, be put into if the major—I have grave reservations that they would ever put them into their automobiles, but I will assume that they would. They would be putting it in on an optional basis.

Mr. McCandless pointed out some reasons why it would be very difficult to pick up on those options. One reason that I would think of would be the lack of qualified mechanics available to repair this type of engine. Again, that would reduce the option. When that does not move, it is like convertible automobiles. They slowed up on them, and now they think they might move again. That is just another point that I would like to make along the lines of having this engine become acceptable not only to the manufacturers, but to the ultimate consumers.

Mr. **Nightingale**. I think, Mr. Carney, that in reading my history books, the argument back in the early days of the automobile was just the same: How would you ever train someone who was familiar with horses to handle IC engines?

Having spent 12 years in the gas turbine business, I can tell you that the tip clearance on turbine blades is critical—I mean, it is of quite a bit more concern than some of the clearances we have to worry about on the Stirling engine.

I think that the Stirling engine does not offer to a mechanic a great deal of additional knowledge requirement to maintain the engine. We have found that out in working with the people themselves.

Mr. CARNEY. You did refer to your history books. I will refer to mine.

Mr. NIGHTINGALE. OK.

Mr. CARNEY. This type of engine has been around long before the IC. It has been around long before the diesel. Why is it now that you think there will be an appeal for the consumer and the automobile manufacturer?

Mr. NIGHTINGALE. I think that the early Stirling engines were looked upon as being restrictive because of the temperature of the materials, and I do not think the materials were available.

We have, in the short term of this program, in fact, as I pointed out, been able to remove all the cobalt. When we started this program, we started looking at alternative iron-base materials, and in that short timeframe, working with specialists from NASA and specialists from Sweden and at our place, we have been able to come up with three alternatives that are cheap, iron-based materials that we can use. We are now starting to look at the possibility of ceramics.

The question of why didn't the Stirling engine take off—I think it was a little bit more difficult because of the limitation on materials at that time.

Mr. CARNEY. Thank you.

Mr. GLICKMAN. Thank you. We appreciate your testimony.

We have the two gas turbine participants, Garrett/Ford and General Motors' Detroit Diesel Allison Division. It would probably be useful if both of you came up to the table at the same time.

Having Ford and GM at the table together is probably a good thing for America.

Mr. McCANDLESS. Are you going to put a screen between them, Mr. Chairman?

Mr. BOPPART. Well, we ignore each other very well. We have had a lot of practice at that.

Mr. GLICKMAN. The witnesses are Mr. John Boppart, Dr. Ian Macpherson, and Mr. Harold Helms.

Do any of you have a slide show?

Mr. HELMS. I have one, but I do not need to use it.

Mr. GLICKMAN. OK. That is fine.

Mr. McCANDLESS. That chair is reserved for the United Auto Workers. [Laughter.]

Mr. GLICKMAN. Why don't we take them in order of the presentation.

Mr. Boppart and Dr. Macpherson, why don't you begin? Then we will go to Mr. Helms.

As I said, your entire testimony will appear in the record following your oral presentation. Therefore, you may feel free to summarize.

[The prepared statement of Mr. Nightingale follows:]

TESTIMONY OF NOEL P. NIGHTINGALE
MECHANICAL TECHNOLOGY INCORPORATED
LATHAM, NEW YORK
BEFORE
THE SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS
HOUSE OF REPRESENTATIVES

Mr. Chairman, members of the Subcommittee, my name is Noel Nightingale, and I am Program Manager of the Automotive Stirling Engine development program within the Stirling Engine Systems Division of Mechanical Technology Incorporated (MTI). MTI is a high-technology research, development, and manufacturing company located primarily in New York State, with wholly-owned subsidiaries in Michigan and California. The SES Division of MTI consists of approximately 100 people engaged in the development of both kinematic and free-piston Stirling engines for a variety of applications. MTI formed this team in response to a national need for this advanced, energy-efficient technology primarily explored in Europe and Japan. MTI employs the largest group of Stirling engine specialists in the world. They are supported by unique test facilities as well.

Mr. Chairman, my company appreciates the opportunity to appear before this subcommittee. My testimony today will consist of a status report on the Automotive Stirling Engine (ASE) development program which is funded and managed by the Department of Energy under Title III of Public Law 95-238. The project management of the program has been under the NASA/Lewis Research Center. I shall also present a description of our FY '84 Program at a recommended appropriation level of 16 million dollars, a discussion of the goals of the program and indications of growing industry acceptance of the Stirling engine, together with some observations concerning the relative position of the United States, Europe and Japan in the development of this most promising technology. I have also included a set of conclusions. The figures referred to in the text are included, for your convenience, in numerical order at the end of this testimony.

In Section 302(b) of Public Law 95-238, Congress charged the Department of Energy (DOE) to initiate a program leading to the development of an advanced automotive propulsion system. Two basic engine cycles were selected for inclusion in the program: the gas turbine and Stirling. MTI is the prime contractor on the Stirling engine program.

The Stirling engine has the intrinsic theoretical capability of providing the highest efficiency and fuel economy of any engine cycle. This engine also uses continuous external combustion for its heat source, a feature that allows maximum latitude in fuel flexibility while minimizing emission levels.

The automotive Stirling engine program team consists of MTI as prime contractor, United Stirling of Sweden (USAB) as Stirling engine technologists and support group and AM General as engine system integrator. The strategy of the original program to meet the Title III objectives was to transfer Stirling engine technology residing mainly at USAB to the United States and convert it to a form applicable to the automobile. The target completion date was September 1984. The original program logic was to accomplish this goal through two engine generations - Mod I and Mod II.

The FY '81, '82 and '83 budget reductions have altered both the size and timetable of the original program. These reductions delayed the start of the Mod II engine program from 1981 to 1983. In 1982 this subcommittee's recommendation was that the FY '83 Program should include the commencement of the paper design for a Mod II engine system. We are proceeding along those lines since the subcommittee's recommendation fortunately carried through the appropriation process. In order to meet the legislated goals in a timely fashion, FY '84 will be a year in which we finalize the detail design of the Mod II engine system and procure engine hardware - hence, our request for a FY '84 appropriation of 16 million dollars. We expect 13 million dollars to be allocated to the MTI contract from these funds.

NATIONAL BENEFITS

The national benefits resulting from a successful ASE Program are multifaceted:

1. Jobs

   Through the introduction of Stirling technology into American products, new jobs in manufacturing and services, as well as an increase in associated trade employment would result.

2. Technology Expansion

   A developed Stirling technology will provide American companies a wide variety of applications in addition to automotive, including heat pumps, farm machinery, electric generators, military, and solar power.

3. Security

   The multi-fuel capability of the Stirling engine will provide personal and national security in times of petroleum dislocation.

4. Pollution

   The Mod II engine will meet the 1985 emission standards as presented in the Clean Air Act which will contribute to the national effort to upgrade the environment. The exhaust gases of a Stirling engine are so clean that when installed in a vehicle, no catalytic converter is required.

5. Conservation

The Mod II engine will provide at least 30% better fuel economy than internal combustion engines, thereby providing significant improvement in our nation's ability to conserve energy. This improvement is strictly due to engine performance and is independent of any aerodynamic and/or downsizing changes.

6. Noise

The Stirling engine makes considerably less noise than conventional engines without any attempt at noise abatement. For example, a Stirling engine does not require a muffler when installed in a vehicle.

SUMMARY OF FY '82 ACCOMPLISHMENTS

In spite of budget uncertainties and funding cutbacks the ASE program has continued not only to meet scheduled milestones and technical goals, but also to attract the interest of industry. Neither a cost overrun nor underrun exists. The following is a summary of the major accomplishments achieved during 1982.

- We are pleased to report two automotive companies and a major engine manufacturer have shown interest in becoming involved in the evolution of the Stirling engine technology through acquisition of a Mod I engine or a Stirling engine vehicle.

- MTI was visited by two major automobile manufacturers to review the technology advances made in the ASE program and to discuss Mod I and future Mod II engine testing.

- Cummins Engine Company has submitted a written statement pointing out their desire to receive a Mod I engine in late 1983 for test and evaluation at their facility.

- Cummins Engine Company has become interested in using the Stirling engine as a bottoming cycle in their adiabatic diesel for the U.S. Army. This would not have occurred had the ASE program not advanced the state of Stirling engine technology to its current level.

- Manufacturing cost, based on the Reference Engine (Mod II) system design, was reduced to a level that is now competitive with current automotive internal combustion and diesel engines.

- The Mod I was upgraded to contain certain technologies embodied in the Mod II, thus completing the first phase of the Proof-of-Concept Program.

- The major program milestone to test and fully characterize the transient behavior of a Mod I engine was completed on schedule by September 30, 1982.

- Over 1300 engine test hours were accumulated on the four (4) Mod I engines in the program bringing the total engine test hour level to 1800. Figure 1 shows the time profile for the total accumulated test hours.

- The USA built Mod I engine, manufactured by a United States vendor base, was assembled and successfully tested for more than 235 hours.

- Critical component and technology development efforts were initiated in ceramic heat exchangers, seals, mechanical systems and controls.

- Strategic material content, a long term problem in Stirling engines, has by the introduction of high strength low cost iron-based materials, been reduced to levels that are comparable to that found in current automotive engines.

ADVANCED TECHNOLOGIES IN THE UPGRADED MOD I

During the past year the Mod I was upgraded and testing of the first engine is scheduled to begin this month - February 1983. The purpose for upgrading the Mod I was to continue developing technologies for Mod II. By using the Mod I engine important system interactions are evaluated. The major design changes made in the upgraded Mod I were:

- Part-Power Optimization: Further part-power optimization of the engine cycle is necessary to adapt it to the automotive driving cycle where high-efficiency levels are required at low engine speeds.

- Increased Operating Temperature: Increasing the engine hot section operating temperature from 720°C to 820°C improves the engine efficiency. This is due to a basic thermodynamic law which states that the higher the hot section, the higher the engine efficiency provided heat losses to the cooling water do not overcome the gain.

- Low Specific Weight: The weight of the engine was reduced by 100 pounds. The outer diameter of the engine was reduced. The hot section parts, because of part-power reoptimization, became smaller and lighter.

- Increased Efficiency: Losses were reduced in the drive system through an improved bearing design.

- Reduced use of Strategic Materials: A major change required to reduce manufacturing cost is to use low-cost materials void of strategic materials such as cobalt and chromium. No cobalt is used in the upgraded Mod I. A new iron-based material called XF-818 was used in place of cobalt-based HS31 for the cylinder and regenerator housing castings. In addition, the cobalt-based tube material N155 multimet was replaced with an iron-nickel based material called CG27.

ASE PROGRAM ACHIEVEMENTS RELATIVE TO GOALS

The Mod I was the initial phase of the ASE program during which a first generation automotive Stirling engine was designed and tested successfully. At the present time the ASE program is at a critical juncture point. Although the Mod I has been a very successful engine demonstrating specific advantages of the Stirling engine over other engine systems, it is an experimental engine and, therefore, is limited in its ability to demonstrate the full potential of low specific weight and competitive manufacturing cost. The time is appropriate to move into the final phase of the program - the Mod II. Industry has recently responded with interest and a program to provide engines for testing in their facilities is about to be initiated. The differences between the Mod I and Mod II engine systems, however, are large when the following are taken into consideration:

- Manufacturing Cost
- Specific Weight
- Simplicity
- Size
- Fuel Economy
- Automotive Configuration

Although the earlier phases of the program continued to provide information as to the potential of the Stirling engine, industry remained uncommitted until Mod I was available in hardware. Even now, only very early exploratory testing and investigation will be offered. As such, a full commitment by industry to bring the technology to market depends on the success of the Mod II phase of the program. Current financial constraints within industry preclude the investment and risk necessary to advance the technology. Major strides must be made in the areas of weight, size, complexity, and manufacturing cost. Title III legislative goals were established with this necessary step in mind and the Mod II was planned to meet these goals.

MANUFACTURING COST

The Mod I has advanced Stirling engine technologies toward those embodied in the Mod II design. Even though the manufacturing costs are quite far apart between Mod I and Mod II, the ASE program has been able to show steady progress toward important goals for not only cost but also specific weight, efficiency, fuel economy and the elimination of strategic materials.

For the past two years an intensive design effort to reduce the manufacturing cost of the Mod II has been underway. This effort has been completed. Referring to Figure 2, the cross section of the current Mod II is compared to an earlier design of March 1981. There are specific and discernible differences, all for the sake of reducing manufacturing cost or removing complexity. The drive system is a "Vee" configuration rather than "U" shaped, which reduces weight and the number of parts. The engine case is a unified single-piece cast iron block, which is cost effective. The heater is of annular construction rather than canister, which reduces cost by means of the cheaper casting process it allows. The coolers are designed for low cost extruded aluminum material rather than hundreds of separate stainless steel tubes. The main seals and piston rings reflect new simplified designs, which shorten the height of the engine. Ceramic material is used in both the preheater and regenerator, which reduces the cost in both components significantly.

Figure 3 compares the current manufacturing cost estimate of the Mod II to the Mod I and the upgraded Mod I. Estimates for the cost of I.C. and diesel engines are also indicated. The figure shows that improvements have been made in the manufacturing cost of the Mod I but, since it is an experimental engine, they are limited. The Mod II will have the necessary cost reductions to provide industry with an engine system that has an acceptable manufacturing cost.

SPECIFIC WEIGHT

Figure 4 shows the improvements made during the course of the program in lowering specific weight. The program began with the P-40 engine which contained technologies existing in Sweden at that time. The Mod I showed a marked improvement as did the upgraded version of the Mod I. However, the Mod I engine system is restricted in the extent to which specific weight can be reduced. To meet the specific weight goal required for industry acceptance the Mod II needs to be built. It will show that the annular heater head concept coupled with a Vee drive system provides an engine system weight applicable to automotive requirements.

ENGINE EFFICIENCY AND FUEL ECONOMY

Figure 5 shows the improvement made in engine system efficiency during the course of the program. Again, the Mod I and its upgraded version showed marked improvements over the baseline P-40 engine, but fall short of the required goal. The Mod II efficiency level is sufficiently high to provide industry with assurance that when the engine is applied to a vehicle system, high fuel economy will be attained.

High engine efficiency implies improved fuel economy - one of the major objectives in the Title III legislation. Figure 6 depicts the gains made in combined fuel economy during the program. In a vehicle with an EPA inertia weight class of 3000 pounds, early P-40 engines showed combined mileage levels below I.C. engines. The Mod I and the upgraded Mod I show steady improvement relative to the I.C. engine. It will take the Mod II engine, however, to meet the program goal of 30% better fuel economy than that of an I.C. engine. It is felt that a fuel economy level improvement of this magnitude will be attractive for industry to use Stirling engines in automobiles.

STRATEGIC MATERIALS

One of the disadvantages with early Stirling engines was the necessity for using strategic materials in the hot section of the engine. The two major strategic materials are cobalt and chromium. Through an extensive materials development program directed by a team of metallurgists from NASA, USAB and MTI there now exists alternative materials void of cobalt which can withstand the hot environment of the engine. These new materials have been incorporated into the upgraded version of the Mod I. Figure 7 shows that in the upgraded Mod I cobalt has been completely eliminated, as it will be in the Mod II. Chromium, however, cannot be totally eliminated as it is an element contained in stainless steel, also present in I.C. engines. Ceramic material has been used in place of costly stainless steel in the heat exchangers of the Mod II, thereby reducing the amount of chromium significantly. Figure 8 shows the progress made in reducing the amount of chromium compared to an I.C. engine level.

TECHNOLOGY DEVELOPMENT

As mentioned, expensive metallic regenerator matrices have been replaced with ceramic material. Figure 9 shows a Mod I regenerator. Currently, regenerators are made from approximately 700 individual wire mesh sintered screens compressed into a stack as shown magnified on the left of the figure. Although the performance of such a regenerator is superb and contributes significantly to the high-efficiency of the engine, its cost is prohibitive. An alternative design being developed is a ceramic foam material shown magnified on the right of the figure which can be manufactured for 90% less cost and provide the same or better performance as the sintered wire mesh. This design is currently being evaluated for reliability and durability.

Ceramic material is also being considered for use in the engine preheater. The preheater is a heat exchanger which allows combustion exhaust gases to transfer heat to incoming cold air and contributes significantly to the engine's high efficiency. Currently, preheaters are metallic composed of 1100 individual plates welded together to form a complex multipass heat exchanger. With literally over three thousand welds involved, its manufacturing cost is unacceptable. Ceramic preheaters can be manufactured for 56% less cost. A comparison between a metallic and ceramic preheater is shown in Figure 10.

Four Mod I engines have tested actively throughout the year. Each engine has been tested for different purposes providing significant data toward the development of specific components, subsystems and Stirling engine technology. Without the important data received from these engine test programs development in combustion, heat exchangers, materials, controls and seals could not have progressed to the point it is today. Engine data guide the technology development path pursued on tests in research rigs and in analytical design. Figure 11 presents power characteristics for the four engines tested; for the sake of clarity, only the 15 and 5 MPa* mean working gas pressure levels are included. The 15 MPa performance curve represents

* MPa: Megapascal
15 MPa = 150 Atmospheres
= 2205 psi

the maximum available power level at any given engine speed, whereas the 5 MPa curve represents an average power level required in a vehicle system. Note that the total engine-to-engine power variation was less than 10% at all power levels. In addition, the maximum power level achieved by all engines exceeded the minumum level established as the final acceptance criteria. Figure 12 shows efficiency levels attained during engine testing. Again, the data are shown for mean working gas pressures of 15 and 5 MPa. There was a greater variation in efficiency level from engine to engine; however, they did exceed the minimum level established as the final acceptance criteria. These data show engine-to-engine repeatability which is an important characteristic use by industry in establishing standard performance levels.

One Mod I engine is dedicated to the development of transient systems such as emissions and controls. To provide this capability the engine was installed in an AMC Lerma Transient Test Bed (TTB) for optimization of engine/vehicle system interfaces. A picture of the TTB is shown in Figure 13. A major program milestone to evaluate the transient characteristics of the Mod I engine by September 1982 was accomplished on schedule using the TTB. Three separate tests, each consisting of a cold start urban cycle and a highway cycle, were conducted using unleaded gasoline. Test results with projections are shown in Table 1. The combined mileage data agreed within 3% of projection which is important since the same analysis is used to project the Mod II fuel economy. Secondly, the emission levels for hydrocarbons are well below the program goal of 0.41 gm/mile. Carbon monoxide emission data met the goal of 3.4 gm/mile. The NOx level was 0.9 compared to a goal of 1.0 gm/mile. The NOx emissions will be reduced to 0.4 gm/mile on the Mod II engine system. It should be emphasized that transient testing of an engine system is not only the most cost effective, but also the most technically sound method of evaluating emission levels. The complex interactions within the combustion system and the transient response of the air and fuel control system during non-steady-state periods such as startup, accelerations and decelerations is extremely difficult to duplicate in any other set-up. As a result of this success one automotive company has expressed an interest in testing a Mod I engine installed in a vehicle.

TABLE 1

MOD I ENGINE TRANSIENT TEST DATA*

DESCRIPTION	URBAN				HIGHWAY	COMBINED
	HC gm/mi	CO gm/mi	NOx gm/mi	Mileage mpg	Mileage mpg	Mileage mpg
Test No. 1	.23	3.4	.96	19.9	31.7	23.9
Test No. 2	.29	3.3	.90	18.8	32.1	23.2
Test No. 3	.25	3.2	.84	19.2	32.4	23.5
Mean	.26	3.3	.90	19.3	32.1	23.5
PROJECTIONS	-	-	.84	19.1	30.0	22.8

* Unleaded Gasoline

TECHNOLOGY TRANSFER

Another major accomplishment during the past year was the successful assembly and test of a Mod I engine manufactured and built solely in the United States. This accomplishment demonstrated the degree to which Stirling engine technology has been transferred to the United States. The engine was tested for the first time in August 1982 and successfully passed acceptance testing with engine power and efficiency levels above the average of the other three engines in the program as reflected in Figures 11 and 12 respectively. The engine has shown excellent reliability and durability having tested for 240 hours in a five month period.

More than thirty separate vendors were established throughout the U.S.A. to support this effort. A few of the vendor types and their locations were:

Investment Casting	Oregon
Crankshafts	Michigan
Brazing Fabrication	Ohio
Machining	New York Connecticut
Piston - Deep Drawing	New Jersey
Ceramics	New Jersey
Tube Bending	New Hampshire Connecticut
Aluminum Casting	New York
Raw Material Tubing	Pennsylvania
Transducers	California
Stamping	Wisconsin

PROPOSED FY '84 PROGRAM

The program that we propose for FY '84 will include the final design of the Mod II and the procurement of long-lead-time hardware for the engine system. The timing of these actions will be in logical sequence to the Mod II component and technology development efforts currently underway and scheduled throughout FY '83 and FY '84. Our program will allow the development of a Mod II engine system with its associated advanced technology to reach a level which will contribute significantly to industry acceptance of Stirling technology. It will also make possible the attainment of legislated goals and completion of the transfer of Stirling engine technology from Europe to the United States. Specifically, the FY '84 program will include the following initiatives:

- Development of advanced technologies to reduce the manufacturing cost of the Mod II engine, namely ceramic heat exchangers, aluminum coolers and annular heater heads fabricated from low-cost iron-based materials.

- Continuation of the development of advanced sealing systems to provide the level of reliability and durability required for industry acceptance of the Mod II engine.

- A comprehensive engine test program to establish system reliability and durability levels acceptable to industry.

- The use of Mod I and upgraded Mod I engines to demonstrate critical technologies required for the Mod II to lower specific weight, reduce size, increase efficiency, lower emission levels and increase fuel economy.

- Support and maintenance of the industry test and evaluation program at industry company sites.

- Demonstration of the transfer of Stirling engine technology through component development, design and analysis of the Mod II engine system.

INDUSTRY TEST AND EVALUATION PROGRAM

A program has been planned to provide two Mod I engines to automotive and/or engine manufacturing industry companies for test and evaluation. Currently a letter has been received from Cummins Engine Company indicating their desire to receive an engine in the fourth quarter of 1983 for a 12 month test program at their own facilities. Other companies are still evaluating their resource capability to test an engine. MTI's involvement will be to procure, assemble and pre-test two engines, provide for sufficient spare hardware, and provide training to industry personnel. These training sessions will be held at MTI prior to engine delivery to company sites. In addition, MTI will provide on-site support to the industry personnel to assist them during their test program.

This program is considered a major step toward fulfilling the original purpose for the ASE program within the Title III legislation by allowing industry to become familiar with Stirling engine technology. By virtue of this program, companies will be able to evaluate the true potential of Stirling. The program will also provide a stepping stone to their evaluation of the Mod II engine system and its readiness to enter a preproduction phase.

The interest shown in this program is only one indication of growing industry acceptance. NASA conducted a survey of various companies in early 1982 to evaluate the level of awareness of Stirling engine technology and its acceptance. In all cases the companies were aware of the advances being made in the ASE program and fully supported its continuation. The technology was felt to be adaptable for various applications including automobiles and light duty vehicles. All companies expressed support for the program. They were restricted, however, in their ability to become involved due to limited resources.

There are growing indications that the Stirling engine may also lend itself to military applications either in vehicle systems or stationary electrical generation. The possibilities arise due to the Stirling's ability to use multi-fuels, its low noise level and cool exhaust gases.

FOREIGN COMPETITION

There is strong evidence that foreign governments and companies are actively pursuing the development of Stirling engine technologies. This topic was addressed at length in MTI's testimony before this subcommittee last year, including a translation of a newspaper article on Japan's "Moonlight Plan". It is known that development efforts are underway not only in Japan, but also in France, West Germany and Sweden. Three years ago Daimler-Benz acquired three P-40 engines from USAB together with an option for licensing. They have accomplished a significant amount of engine testing and currently are evaluating an engine in a light-duty van and on a dynomometer. The French government is known to be studying the use of Stirling engines for submarine applications.

NASA visited Japan in June 1982 to obtain insight into their gove[illegible]nt/industry/university cooperative research method and to determine the objectives, status and plans for Stirling research. Visits were made to the University of Tokyo, Nissan Motor Company, Aisin Seiki Company (Toyota Group), Yanmar Diesel Engine Company, Diahutsu Motor Company and Diahatsu Diesel Manufacturing Company. NASA found that a Stirling development project has started with funding for approximately 40 million dollars (between 1982 and 1988). There will be several companies involved aimed at the development of 3 Kw heat pumps and 30 Kw generator sets. It was found that considerable computer code analysis is underway at the University. Ceramic development was also being pursued. Marine Stirling research was conducted at Diahatsu during years 1976 to 1981. Conclusions from this trip were that the government/industry/university relationships in technology development appear to depend heavily on carefully establishing a strong initial constituency, a stable long-term government commitment, a strong university review system and a cooperative attitude among companies. Finally, it was concluded that there is a serious long-term government/industry commitment to developing Stirling technology characterized by a new six year $40M government program, major company commitments, and automotive company interest. It was felt that their current technology level is behind the ASE program and that there is a strong awareness of our program.

CONCLUSION

In conclusion, Mr. Chairman, I would like to summarize by stating the following:

1. The ASE program is a successful example of the type of program that should be supported by the Federal Government to address major national needs.

2. The original goals of Title III of Public Law 95-238 are still valid and in the public's interest.

3. During FY '84 the required technologies will have been developed to the point where a Mod II engine system could be built and tested to meet these goals, thereby providing a technology level that can be assumed by the U.S. industry.

4. There is no evidence that U.S. industry is in a position to pursue development of Stirling technology without substantial Government support. It is necessary for this program to provide a Mod II engine system in hardware which the industry can assume without extensive development costs.

5. Stirling engine technology is receiving increased attention and support by foreign governments and companies which may lead to a broad array of energy-efficient products that could cause further domestic economic dislocation in the United States.

Thank you, Mr. Chairman, for this opportunity of appearing before this important subcommittee. I would be pleased to answer any questions which you or other members may have at this time.

AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM

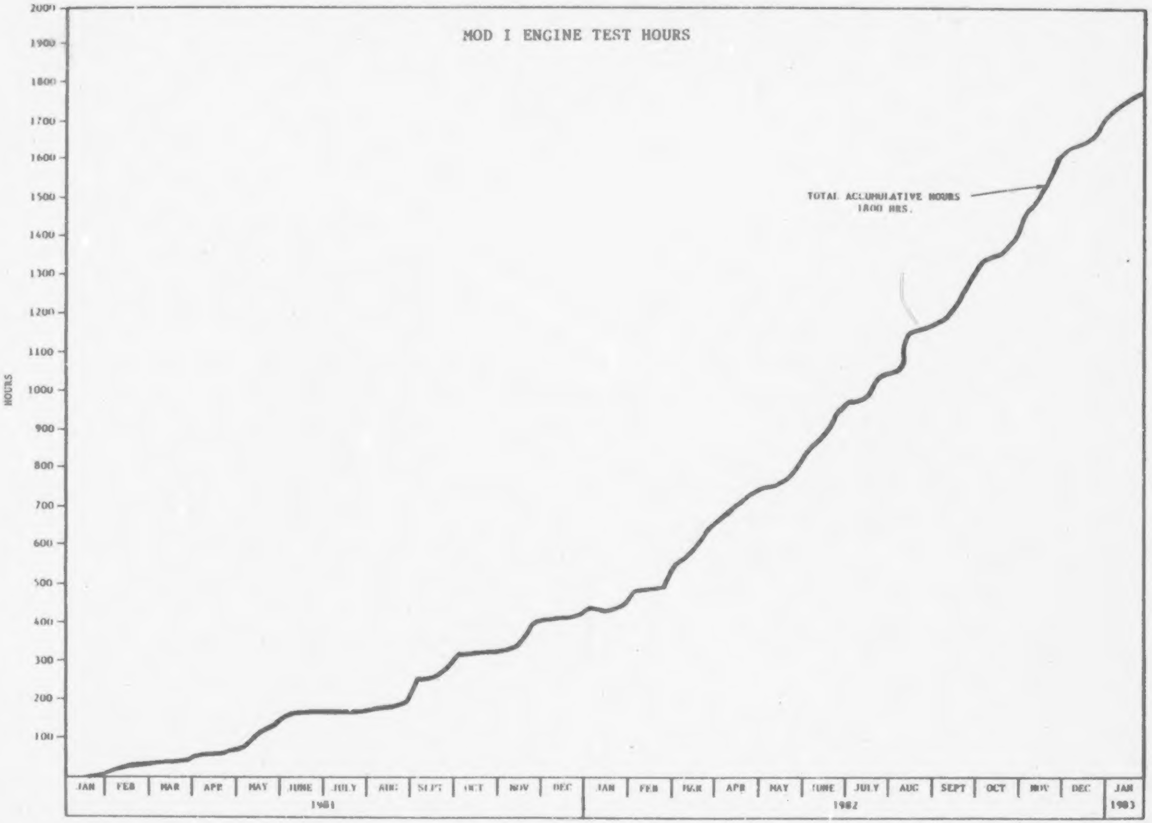


FIGURE 1

AUTOMOTIVE STIRLINE ENGINE DEVELOPMENT PROGRAM

MOD II COST REDUCTIONS

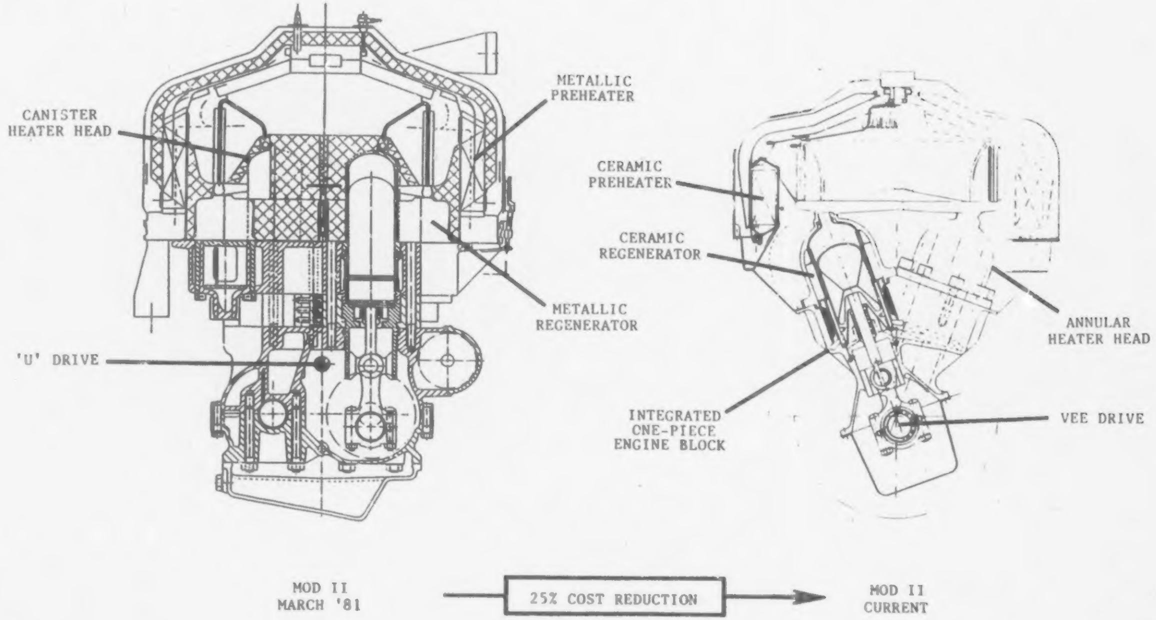


FIGURE 2

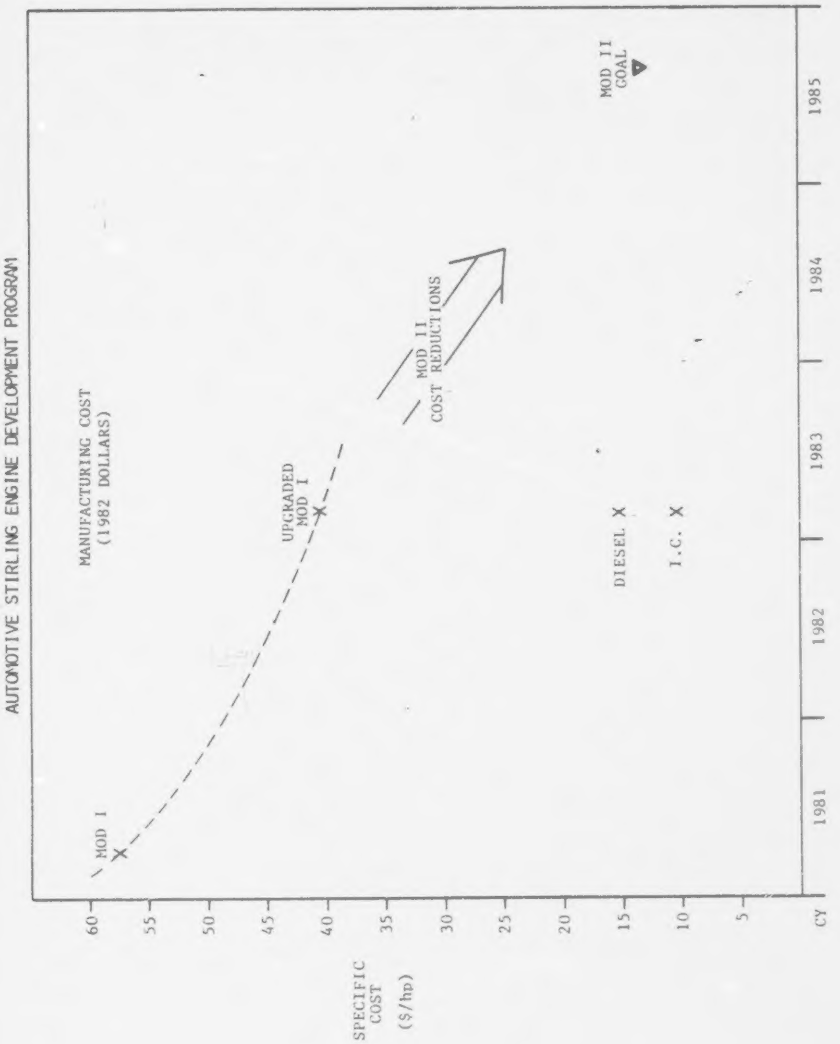

AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM
MANUFACTURING COST
(1982 DOLLARS)
SPECIFIC
COST
($/hp)
60
55
50
45
40
35
30
25
20
15
10
5
CY
1981
1982
1983
1984
1985
MOD I
UPGRADED
MOD I
MOD II
COST REDUCTIONS
MOD II
GOAL
DIESEL
I.C.

FIGURE 3

AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM

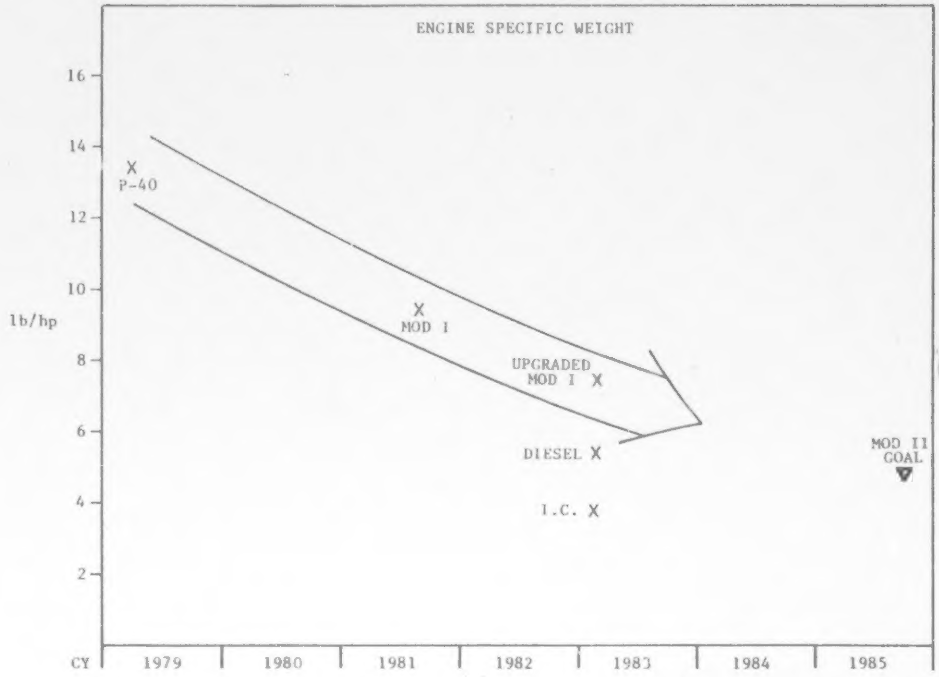


FIGURE 4

AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM

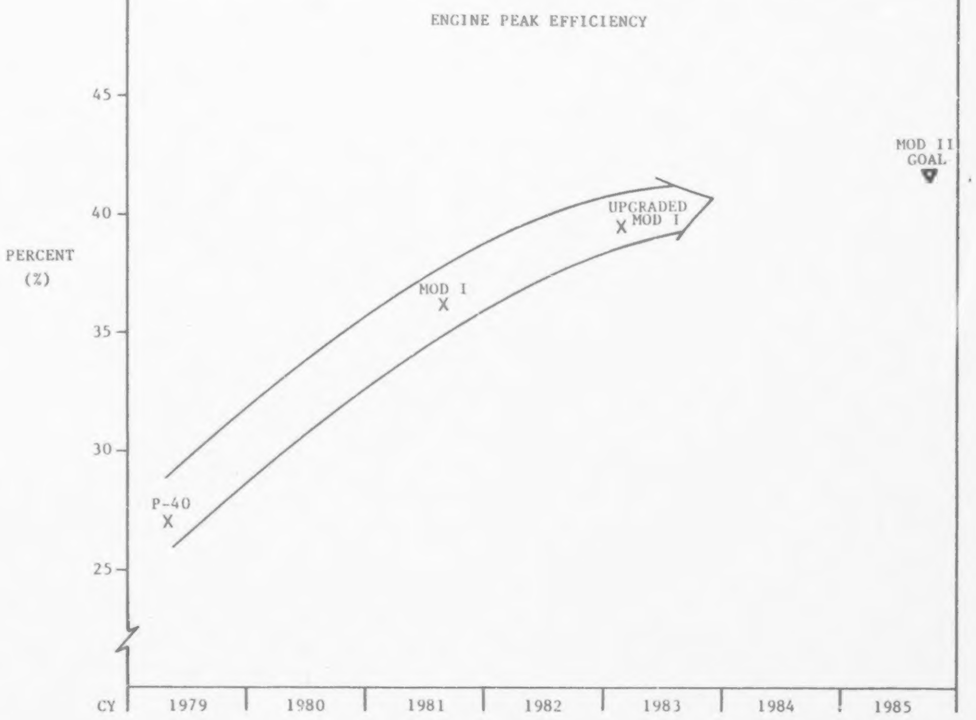
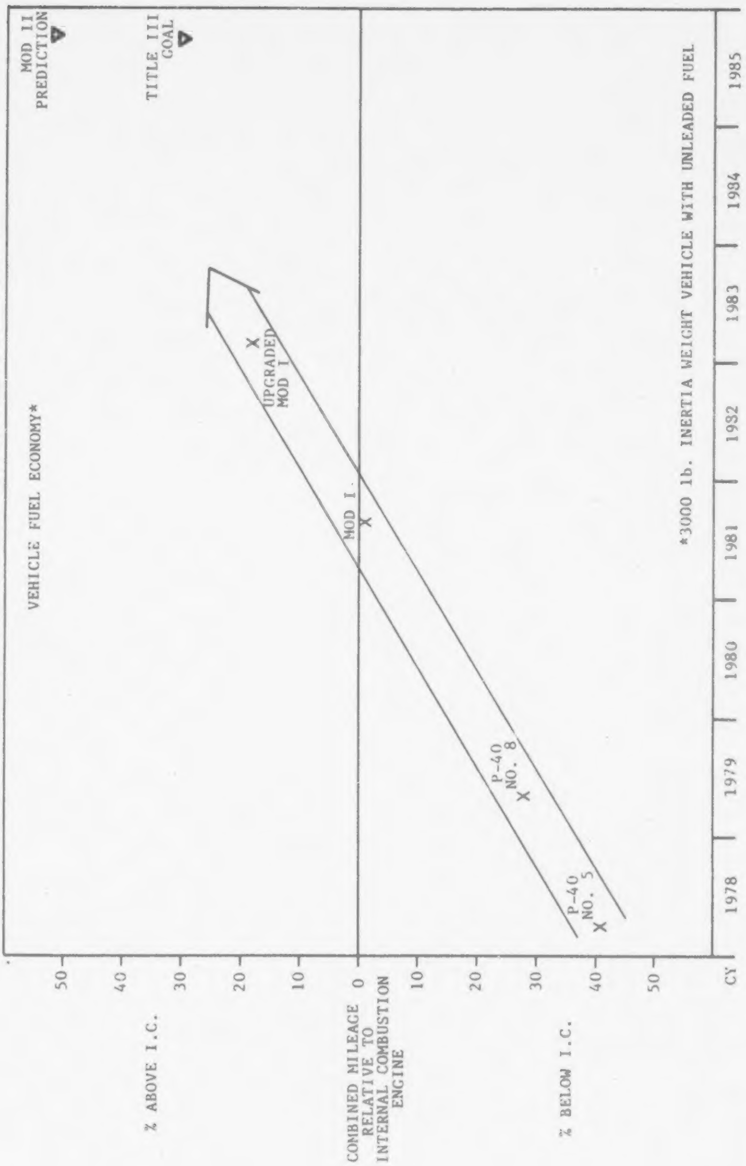


FIGURE 5

AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM



*3000 lb. INERTIA WEIGHT VEHICLE WITH UNLEADED FUEL

FIGURE 6

AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM

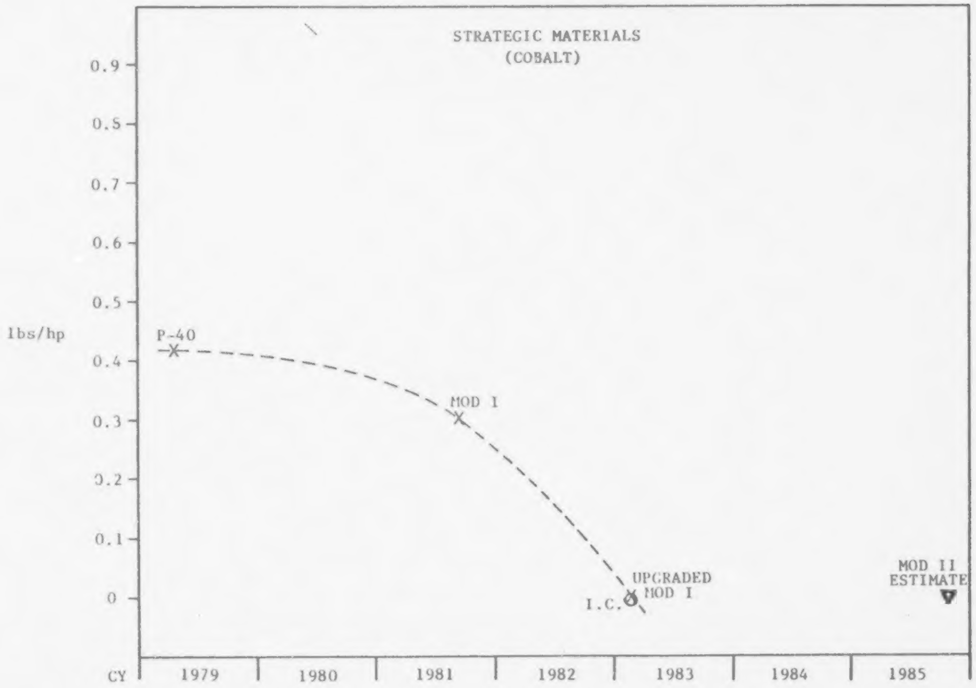


FIGURE 7

AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM

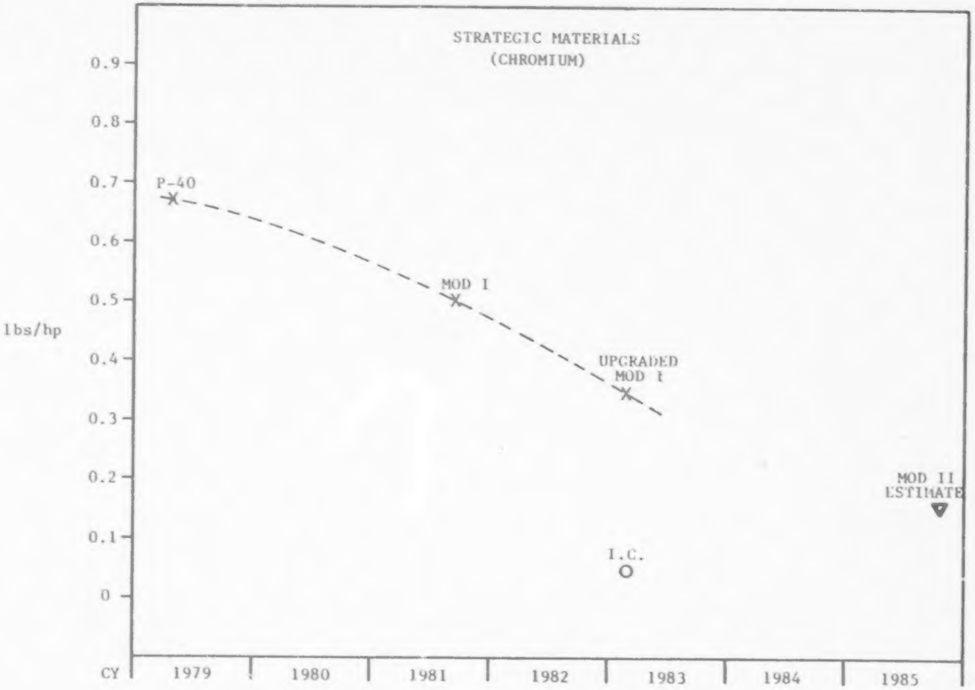


FIGURE 8

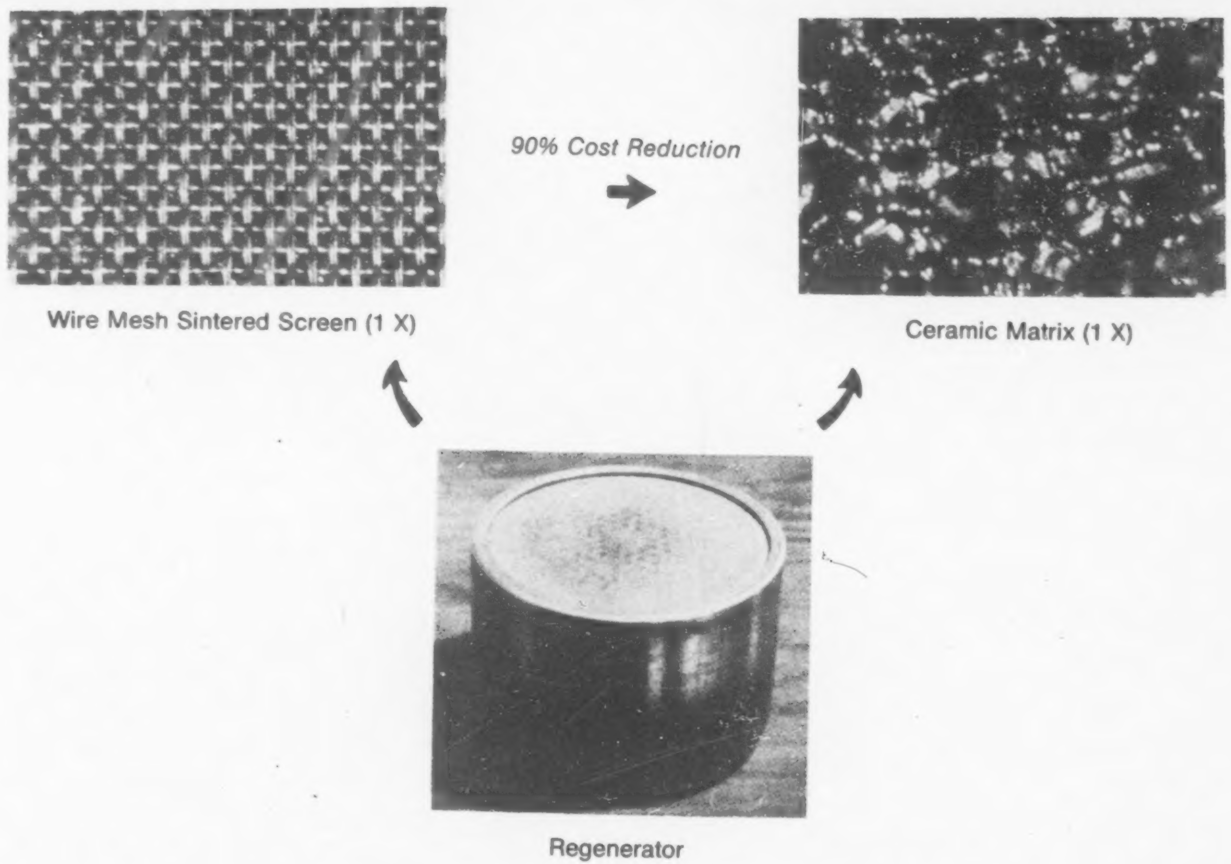


Fig. 9 Comparison of Regenerator Matrix Material

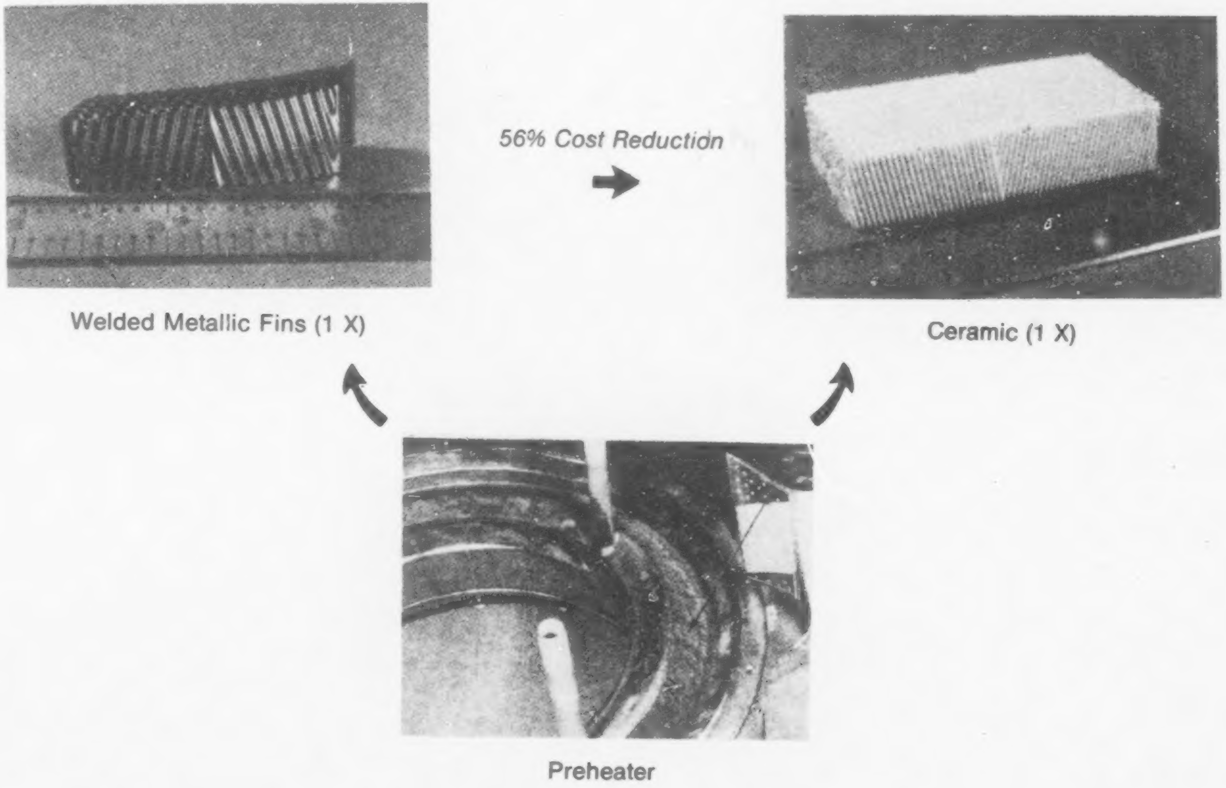


Fig. 10 Comparison of Preheater Material

AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM

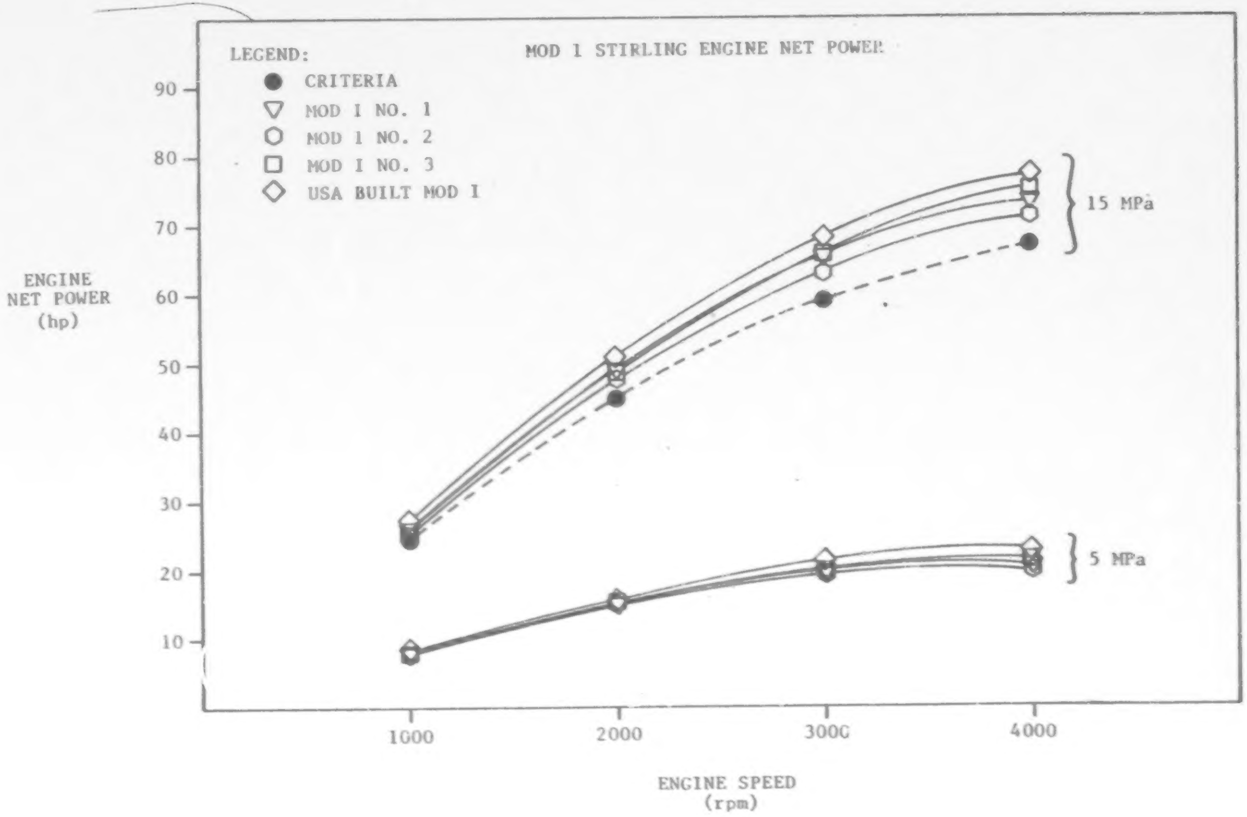


FIGURE 11

AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM

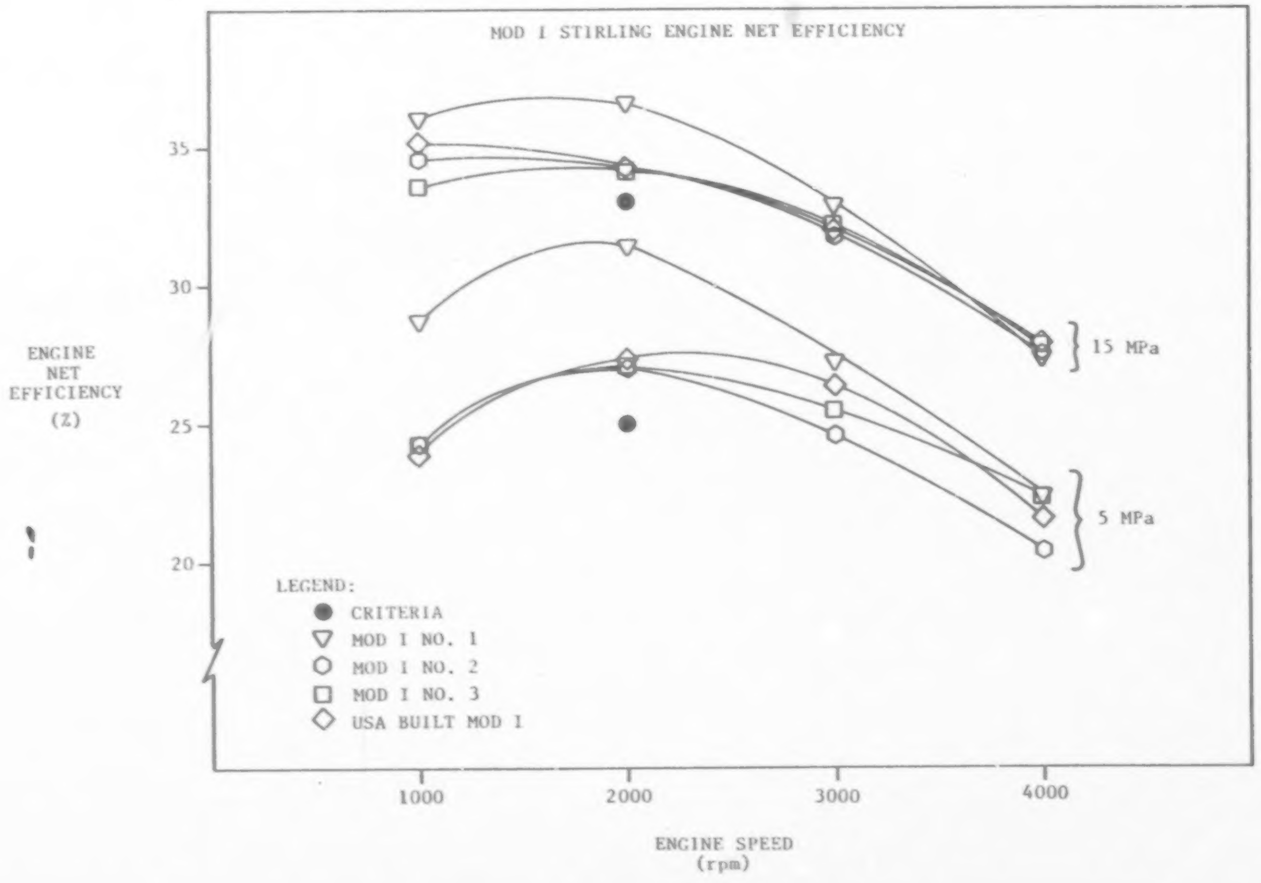


FIGURE 12

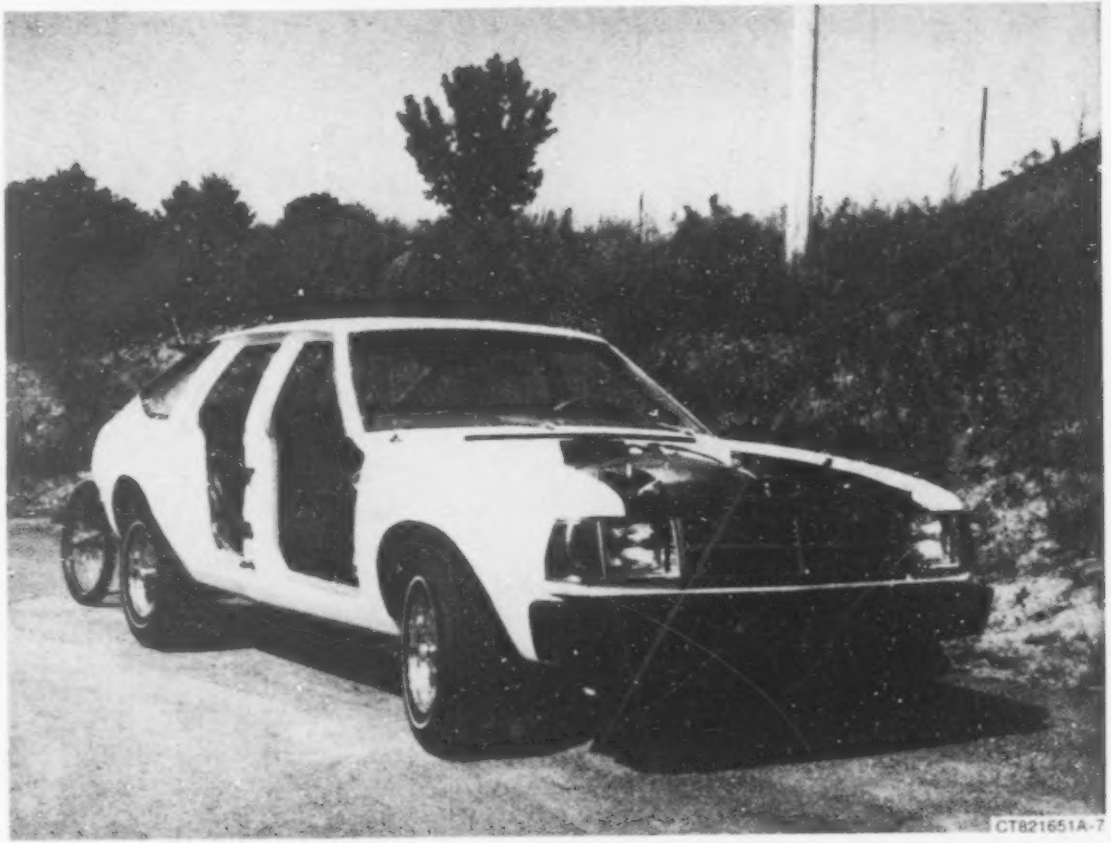


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Fig. 13 Mod I Engine Installation in Transient Test Bed

STATEMENT OF JOHN BOPPART, VICE PRESIDENT OF ENGINEERING, GARRETT TURBINE ENGINE CO.

Mr. BOPPART. Fine.

In response to your request, I will not read our testimony. You may wish to refer to it for some illustrative material.

As indicated, I am John Boppart. I am vice president of engineering for Garrett Turbine Engine Co. Dr. Ian Macpherson is director of Powertrain Research Laboratory for the Ford Motor Co.

We have given you an illustration of who Garrett is. We are part of Signal, which has recently merged with Wheelabrater Frey. We are, thus, very active in the energy and energy conversion business in general.

In particular, we have combined in this program to work on a very long-term, high-risk technology suitable for automotive gas turbines in future automotive and other power plants.

This is the third year in which we have provided testimony. In previous years we have discussed the benefits of this program to the Nation at some length. Rather than reiterate that in today's testimony, I would like to focus on what I think is very significant progress that the program has been making and where we think we will go from here.

First, I think we ought to reemphasize that the technology continues to be of critical importance. I would like to quote Dr. George Keyworth, the Science Advisor to the President, in a recent speech. He began by saying:

> Isn't it incredible that the United States has the greatest science enterprise the world has ever known—yet we watch, seemingly powerless, as foreign industries turn our science and technology into products that capture our own markets? Something is obviously wrong.

I think this program relates very closely to that.

The automobile industry continues to have strong foreign competition, and we feel that this is a particularly critical area in which the Government should continue to support the automotive industry.

This program was originally established in 1979. It has since been restructured as a long-range, high-risk technology-development program with the objective of developing the technology base which would support a production automotive gas turbine.

Garrett brings to this program our background as a leading manufacturer and designer of both turbochargers and small gas turbine engines. Ford, of course, brings their expertise in the automotive industry and their expertise in ceramics.

As shown on figure 2, we also make use of a wide range of supporting subcontractors throughout the ceramics industry.

We remind you, in figures 4 and 5 on the next page, that ceramics are made primarily of silicon and carbon or nitrogen, which are extremely plentiful elements in our world and, thus, tend to lend themselves to very low cost materials. By contrast, the strategic materials, super alloys, conventionally used in gas turbines are very expensive and scarce materials. Therefore, the incentive to develop structural ceramics for gas turbine engines.

I think that we have mentioned the foreign competition in this area, and I think one rather interesting example of this that I came across the other day is this: This is the cover of a currently popular novel in Japan. It is kind of a counterpart to the novel here a few years ago called, "The Crash of '79," in that it is a futuristic novel. The plot of this novel has to do with the dreadful impact on the Japanese automobile industry in 1985 by the surprise introduction into the Japanese market of a revolutionary car with a ceramic engine by a U.S. manufacturer. So the subject is at least getting lots of attention overseas.

Now I would like to focus for most of my discussion on the very significant progress that we have been making in this program.

We started out with the objective of demonstrating a combined driving cycle mileage of 42.8 miles per gallon in a 3,000-pound car. As I will show you a little later, we now, in fact, predict that we will do substantially better than that.

The program is aimed at multifuel usage. The engine that we started to develop and continue to carry on as a representative test bed, which is shown in figure 6, is a 100-horsepower engine operating at 100,000 rpm's with peak temperatures of 2,500° Fahrenheit.

The key features of this engine are the simple rotating assembly. You see an actual assembly there with an aluminum compressor and a ceramic turbine. That is the major moving part in the engine.

A ceramic rotating regenerator is used to recover waste heat. This is an example of the material that the regenerator is made out of.

To date in the program we have experienced substantial success in proving the feasibility of the manufacture of these ceramic parts. Figure 7 illustrates a large variety of actual ceramic parts that have been supplied by the ceramic manufacturing team supporting this program.

We have been operating both aerodynamic and ceramic test rigs. You will note in figure 8 that our testing has now accomplished 3,900 hours on the component test level.

Within the last year or so we have begun to run actual metal engines, which are to be test rigs for the further development of the ceramics. We have operated three engines of the configuration shown at the left of figure 9, which is essentially an all-metal initial engine.

We have operated each of these engines to the full speed of 100,000 rpm's, and have totally accumulated about 127 hours of operation. We are now in the process of moving toward the configuration shown in the center of figure 9, in which we will incorporate the major ceramic parts and begin to prove their feasibility.

In addition to this basic program, one of the engines that we presently have in our test program is slated for a solar application, and that is illustrated in figure 10. The engine is matched to a solar receiver for a test under another program sponsored by DOE, NASA, and the Jet Propulsion Laboratory.

An aspect I would like to emphasize is our ceramic progress. When we began, it was not at all obvious that it was possible to make a bladed ceramic turbine of the stress levels required for an automotive gas turbine or how to do it. A number of breakthroughs in the manufacture and processing of ceramic parts were required. All of those parts have now been fabricated and their feasibility has been demonstrated at or very near the levels at least initially required for engine testing.

We have run each of the ceramic structural parts individually to 2,100° Fahrenheit in test rig and are expanding our testing in a structures test rig shown in figure 12, in which all of the ceramic structures, other than the actual rotor, can be put into a rig at once and thermally cycled and exposed to real engine operating conditions.

We have successfully qualified a full set of ceramic parts up to 1,600 degrees during the last year. We are currently in the process of working toward 2,000° for the same assembly.

I think it is necessary to reiterate the point that the development of ceramics for gas turbine is somewhat peculiar in terms of development of materials for engines in the past due, to some pecularities associated with ceramics.

In developing advanced metals, we are perhaps all aware that a great deal of work is done in the laboratory, that a great deal of work can be done on small test specimen, because the capability exists to take properties of metals measured and proven in small test specimens; use that data to design engines, large parts, anything one would care to; and have reliable results. The same is not true of ceramics, and this is due to the fact that the inherent capability and the inherent stress capability of ceramic materials is not only a function of the formulation and the processing, as is the case with metals also, but is a function of the size and shape of the part being made.

A given level of technology which may be very satisfactory on a small ceramic part may not be satisfactory in a somewhat larger ceramic part. Therefore, in order to make real progress and know that the investment in technology development of ceramics is being made properly, it is necessary to do the work in test beds like our prototype engine and in configurations that are truly representative of an engine configuration.

We have accomplished a great deal, as we have indicated here. We originally had four contractors working on the rotor. Two of them, AiResearch Casting Co. and Ford, have been successful in showing they have the capability of making the units of the size required for the rotor. We have now selected these two as being the best, and they are proceeding to actual bladed rotor development and have had some good success in spin testing.

The successes that we have accomplished thus far are extremely encouraging to us. However, I want to emphasize that these only represent the very beginning of the evolution of ceramics. A great deal more work is required to get to a point where the technology would be regarded by an automotive company as being ready to develop into production.

The program that we have been conducting is illustrated in figure 14. It is aimed at proof of technological readiness in 1985.

Although the budgets have been reduced considerably from those that were foreseen at the beginning of the program, I think we have done reasonably well in staying on schedule and staying with the accomplishment milestones.

I think that figure 14 deals specifically with the question you asked, Mr. Glickman, with regard to what do we consider to be the point at which the Government's role should end and the normal industry evolution should take over.

We believe that if we are able to proceed at the present rate, and with the kind of program we contemplate for the next 2 years, that by the end of fiscal 1985 we will have proven the technical feasibility of ceramics in the kinds of configurations required for automotive engines and that the technology will then be in a state in which automotive companies can pick it up and go into their preproduction development activities. Dr. Macpherson will wish to comment on that further in his testimony.

We do feel that it is very important to continue to aim for accomplishment by the end of 1985, both because of the feelings of our partners at Ford as to what is required for automotive competitiveness and simply in order to have an orderly and a fruitful program.

The funding level, as I mentioned, has not been as originally contemplated since 1981. We are funded at a level to us, to our contractor team, of $8.5 million this year. We believe that our contractor team will require about $12 million in each of fiscal 1984 and 1985 in order to accomplish the program goals at that time.

We should mention that,in addition to the automotive requirements, the engine is being evaluated for a number of other uses. We have illustrated the solar thermal generator set, the groundbase generator set, truck and farm vehicle propulsion, which are also major opportunities.

As I mentioned before, we have become more optimistic about the fuel economies that can be accomplished. We now believe that in the range of 45 to 50 miles per gallon is very reasonable to expect.

In summing up our testimony today, I want to emphasize again that we regard this as a long-range, high-risk technology program. We feel that it is clearly of a high-risk nature, such that, without Government support, although we and Ford, I am sure, will try to pursue it without Government support, you cannot expect that this technology will reach production capability in a time span that we think will be competitive with what is being done by the heavily subsidized Japanese program.

Perhaps in support of that, I would like to cite, and I will introduce as part of our submittal, a recent report from the Argonne National Laboratory, prepared for the Department of Energy. The title is, "The Structural Ceramics Research Program, A Preliminary Economic Analysis." It is a very detailed and thorough report, and it illustrates the author's conclusions that, whether we or foreign competitors are the first to be successful in developing and putting into production this advanced ceramic technology will make a difference of hundreds of billions of dollars over a 10- or 20-year period in the gross national product and then in the trade balances between ourselves and overseas nations.

Therefore, we continue to recommend that the program be funded at the level we have recommended and be aimed at timely completion of this technological feasibility demonstration by the end of fiscal 1985.

At this point I would like to turn it over to Dr. Macpherson.

STATEMENT OF DR. IAN MACPHERSON, DIRECTOR, POWERTRAIN RESEARCH LABORATORY, FORD MOTOR CO.

Dr. MACPHERSON. Mr. Chairman, if I may carry on, my formal submission starts on page 14. I will, however, summarize the contents.

I would like to bring in three distinct elements to this presentation.

First is to say a few words about the powertrain as a concept, why we think there is a potential product there for the Ford Motor Co.

The second is to spend some time on the spinoff we see from the ceramic technology.

The third is to spend a few moments on the subject of the time scale of a possible application.

If I can remind the committee, we are thinking of a powertrain which not only has the gas turbine, but also has an advanced form of gearbox, one which we refer to as a continuously variable transmission. On page 15 you will see a rather complicated diagram which shows the inside of such a transmission.

It is this combination, the prime mover and the transmission, which will enable us to get the fuel economy we need on the road.

In John Boppart's formal submission, you will see that we are aiming for miles per gallon that are approaching 50 in a 3,000-pound car, and therefore, we have to think of the total powertrain concept.

If I can move on to my second subject, this is one we see of considerable importance in the Ford Motor Co. This is the spinoff from the advanced technology dealing with ceramics that we are all challenging and facing in the AGT—the spinoff of that ceramics technology into other aspects of industrial activity.

A very simple example is that Ford has recently announced the evolution of some new cutting materials. I have some here, and I would like to show them to the committee later on.

We now have experience of cutting cast iron with ceramic tips of exactly the same composition as the rotor in front of us. These cutting tools are showing a considerable benefit over the most highly developed cutting tools in current use. And clearly, this is one important aspect of some of the spinoffs.

Not only do we see these new applications, but we are, under our own expenditures, investigating the use of ceramics in other forms of engines. Here I am thinking of diesel engines in particular.

To summarize, we are thinking of this program, where we all recognize that we are reaching for the limits of ceramic technology, as one that will lay the foundation for wider applications of this technology.

If I can just touch on the third aspect, I think this is a subject of considerable interest to the committee. This is the question of the time scale between the successful achievement in the laboratory of a working prototype and the eventual introduction into a mass-produced automotive product. I am not sure the committee is aware of some of the time scales involved in industry today, but it is a fact that between the initial concept of a new engine and its introduction on the production line, it is not unusual to think of the time span of 7 years. Within that period, certainly after the first two, we would expect to have gotten to the stage where we have a working prototype demonstrating the technical capability that is the key element in that engine.

It follows that even when we get to the end of this technology demonstration and we have successfully found that this engine will operate, there will be an extended period of further proveouts and further trials, perhaps in a pilot program, before we could achieve a large-scale production in an automotive application.

Now, in conclusion, I would like to stress that we have found the progress made over the past 12 months of considerable encouragement. There have been some major strides, both in the operation of the mechanical parts of the rotor system and particularly in some of the ceramics technology. We do expect that the continuing efforts in 1984 and 1985 will be successful in demonstrating the goals of the program.

Thank you, Mr. Chairman.

Mr. GLICKMAN. Thank you, Dr. Macpherson.

Mr. GLICKMAN. Mr. Helms, why don't you proceed now?

STATEMENT OF HAROLD E. HELMS, ACTING CHIEF ENGINEER, ADVANCED GAS TURBINES, DETROIT DIESEL ALLISON DIVISION, GENERAL MOTORS CORP.

Mr. HELMS. Thank you very much, Mr. Chairman.

I would like to first address a point that I believe is important. I have heard it mentioned several times today, that there are many kinds of powerplants. There has been an historical look at all kinds of powerplants, such as the Stirling engine, the turbine engine, the diesel engine, and the spark ignition engine, but I think, very specifically, the heat engine program that we, at the start of these programs were discussing, was prompted by a study by the Jet Propulsion Laboratories, which identified a ranking of efficiency levels in powerplants.

Now we have not achieved in these powerplants the success with materials that is required to meet all of the marketplace criteria. Those marketplace criteria are simple. They are cost, performance, and reliability. However, thermal efficiency in powerplants can be achieved if you can do certain things.

Therefore, the thing that is new and the thing that is so encouraging is that we have, all of a sudden, at our disposal these ceramic materials which offer the higher operating temperature capabilities that we have not had in the past. If we apply the new technologies to some of these advanced cycle engines, they have the potential to be very significant relative to fuel conservation; they also have the potential to be extremely inexpensive to introduce into the marketplace.

With that introductory comment, I think that there is a real rationale for the projects and I think that they are very realistic.

The project we have been conducting with the Department of Energy and NASA has a history dating back to 1976. We have had, in fact, two programs, one which was called CATE, and that stands for ceramic applications in turbine engines, and we have now accumulated 9,400 operating hours in that engine with ceramic components. We think this begins to show the feasibility of these exciting new materials that offer a possibility to achieve the thermal efficiencies in some of the advanced powerplants.

The AGT program, with its goal of 30 percent improvement over a spark ignition engine, gives us the opportunity to pursue this high-risk area and see if we can truly capitalize on what is offered here by some advanced technology.

We have identified in our project two key technology areas, the ceramic materials, and the other one is the small scale involved in production automotive turbines. That is a very important factor to us, because I do not think anyone has produced in production quantities turbines as small as we talk about. The turbines you are used to seeing are those on aircraft and industrial oil-gas turbines, and so forth. These turbine engines are flowing air flows less than a pound per second, where most of the aircraft engines you ride are 150 pounds per second or 300 pounds per second of airflow.

Therefore, the small size of these pieces and maintaining the efficiencies in that small size, is a very important project element along with the ceramic material.

These are two key technology areas, and I want to make sure we call that to your attention.

The approach we have used at General Motors in addressing the turbine is that we again go back to these key marketplace criteria: Cost, performance, and reliability. We chose our engine very deliberately because we wanted to be able to meet these criteria.

We have teamed and worked with our partners at Pontiac, and Pontiac has done a continuing cost analysis to make sure we can make this turbine be competitive in the marketplace. We believe we are approaching that point now. The only real unknowns that we have are those that pertain to the undetermined processing parameters with the ceramics and the inspection tools that are to be used for the ceramics, and, finally, the specifications you have to have with ceramics in a production environment.

In the testimony—and I have brushed over this very rapidly—we have had a team that we have worked with which has included many ceramic suppliers, both American and foreign. We have endeavored at all times to spend our development moneys on ceramics with American suppliers, however, and, very specifically, with the Carborundum Co., GTE, and with the Corning Co. Those are the companies that have received the development moneys which would enlarge and improve their technologies.

In this past year we have begun testing our first engine, and we are in what I call a shakedown phase of testing. We will bring a second engine onstream May 1, a third engine in October, a fourth engine next year in 1984. We believe those four engines will give us the capability to properly assess ceramic performance in a realistic environment. It will give us the ability to assess initially the reliability of these ceramic components and, very importantly, it will give us the capability of characterizing the performance we will get in these engines.

I, too, would like to call your attention to special ceramics progress. I have here before me a rotor, and this shape represents a size before the ceramic rotor is fired, and this represents the rotor after having been sintered. There is a shrinkage of 20 to 25 percent, depending upon the kind of ceramic.

One of the technical challenges we faced is, how do you control that shrinkage in a manner that you can maintain tolerances required aerodynamically and still get the proper finishes required structurally? We feel a real breakthrough has been made by the Carborundum Co. They were the first to make such a rotor.

We have now proceeded to make a rotor on our own funding that would be a truck size rotor. It would be an enlarged AGT-100 type engine. We look forward to pursuing that under our own funding or with your help, perhaps, in the future.

I would also call your attention to figure No. 4. I think figure No. 4 is a representation of a very unique photograph. This is a picture of such a rotor, as you see here, at the instant of burst. The rotor is rotating at 111,000 revolutions per minute.

Using this kind of photography, and also using some very advanced, nondestructive inspection techniques, such as acoustical measurements, we are beginning to find extremely small defects in these ceramic materials, which is a key in being able to use these kinds of materials in heat engines and other applications.

Figure No. 5 shows a picture of emissions. We note, with you, that the emission level achieved in NO_x is less than 10 percent of the 1985 standard.

Figure No. 6 shows a schedule quite similar to Mr. Boppart's, showing activities that we require to complete the program.

I would like to read to you our funding requirements.

The AGT 100 project originally consisted of a $65 million, 68-month program. It currently is a $57.7 million, 72-month program. Fiscal years 1983, 1984, and 1985 remain to be completed. Vehicle testing has been eliminated from our project and emphasis placed on technology. Successful completion of the engine and technology program will provide very strong motivation for future vehicle evaluations by General Motors of these engines.

Another paragraph I would like to read to you is this:

To continue the AGT 100 project to completion requires a funding level of approximately $33 million. DDA expects to cost share 10 to 20 percent of this amount with the Government. We believe with this level of funding we could carry this program to successful completion. We have discussed with NASA requirements for $8.7 million in 1983, $12 million in 1984, and $9.3 million in 1985. This is consistent with earlier discussions we have had with technical staffers.

I would also like to read one paragraph that I think is very important in your considerations, and that is this:

On March 25, 1981, Mr. Smith, then-vice president of General Motors and general manager of the Detroit Diesel Allison Division, addressed a letter to this committee which reads in part:

> The U.S. Government, through DOE funding, has stimulated industry to address the basic development of a technology which promises to have far-reaching international impact, at a time when risk is high and demands for American corporate funding are at unprecedented levels.

This continues to be the situation today, except that we now observe the threat offered by foreign competition. That has been called to your attention. I will not belabor that.

That concludes my remarks, Mr. Chairman. I will be glad to answer any questions you might have.

Mr. GLICKMAN. First of all, I would like to ask you to briefly define the difference between your two ceramic programs, the two engine programs. Would you do it as briefly as possible without disparaging the other one?

Mr. BOPPART. You can have a shot at me if I do it wrong.

We basically began this thing with two different approaches to what was the right concept on which to design an automotive engine. The DDA engine is a two-shaft, free-turbine engine. The Garrett-Ford approach is a singleshaft engine which has fewer parts in the engine, requires a more complex transmission, however, and also that which was regarded as a real risk in the beginning, it requires a larger single turbine. The turbine which we have in our engine is probably not obvious but it is significantly larger in dimensions and stress level than in the DDA engine. There are some lesser details that continue in the designs.

The DDA engine uses ball bearings. We have used foil gas bearings, which comes from our background in air cycle turbo machinery.

The configurations of the engines are different in some significant ways, I think, that would reflect on the kinds of technology developed. The design of the Garrett-Ford engine, as perhaps you saw from the pictures, heavily emphasizes keeping the parts rather symmetrical and circular. The DDA engine has some ducting parts which are nonsymmetrical and which pose particular challenges in the design of the engine.

There are some significant differences in the kinds of ceramics being developed. Although there are some ceramic materials that we both use, there are some areas in which the two programs use significantly different basic materials and ways of processing them. Therefore, although there is obviously some overlap, there is a considerable increase in breadth of technology because of the two programs.

Mr. GLICKMAN. Mr. Helms?

Mr. HELMS. I believe John is very correct in his assessment in most respects. I would add one point that I feel is very important.

When we chose the engine geometry we looked very carefully again at this cost factor, and we felt it very desirable to choose an engine to work on that could use existing kinds of transmissions. We can use the manual, automatic, and continuously variable transmission. With our engine I think that is unique and different.

I think yours demands, in essence, a continuously variable transmission.

We did that very deliberately because if the turbine is, indeed, successful, we feel that the introduction of the engine needs to cost as little as possible to have a chance of getting into the marketplace.

We can take a V-6 engine out of the "X" body car or an L-4 engine out of the "X" body car and set a turbine in and use identically the same kind of transmission that is there today.

Again, a cost factor that we have chosen to pursue——

Mr. GLICKMAN. I guess what I am trying to say here is this: If, in fact, we acceded to the Department of Energy's desire to converge to one contractor, we would be losing one technological way of proceeding with this development of a ceramic in a gas turbine engine. This worries me very much.

You are sufficiently different at this time that we would lose that technology? Is that a fair statement?

Mr. **Boppart**. Yes.

Mr. **Helms**. Yes.

Mr. **Glickman**. Dr. Macpherson?

Dr. **Macpherson**. If I may just make one comment, please, Mr. Chairman, if we are to envisage the situation in which one contractor's engine goes forward, the second contractor would have to completely redesign his ceramic parts and, therefore, go into a lot more prototype manufacturing activity in order to put those into the same engine.

Mr. **Glickman**. Mr. Helms?

Mr. **Helms**. There is just one comment I would like to make.

I believe that the two programs are extremely complementary and, between the two, address in sufficient depth the technology that we all want, I believe, and need to have in the near-term future.

Mr. **Glickman**. Give me some idea of the funding requirements which you would like to see in the fiscal 1984 budget.

Mr. **Boppart**. There is an indication that each of us would like to see about $12 million come to us as a contracting team.

Mr. **Glickman**. Right now the Department of Energy has $10 million for one and $2 million for the other?

Mr. **Boppart**. I believe that is 10 and 2.

I think we should emphasize—and I believe I understood Mr. Helms to be saying the same thing—that the $12 million figures we speak of are net to us as contractors. The additional funding required for DOE or NASA involvement in the program should be on top of that.

Mr. **Glickman**. If you received the $12 million in fiscal 1984, what would your request be for 1985.

Mr. **Boppart**. It is similar.

Mr. **Helms**. Ours is a little less.

Mr. **Glickman**. If a decision would be made in 1985 to end at this stage of the program, would you proceed without Government involvement at that time?

Mr. **Boppart**. That is my opinion, yes.

Mr. **Glickman**. Is that your opinion, Mr. Helms?

Mr. **Helms**. Right.

Mr. **Glickman**. What about cost-sharing? How are you involved in cost-sharing?

Mr. **Helms**. At this time—and, again, as I noted in the testimony—we are cost-sharing to the extent of 10 percent this year and would expect to cost-share at the approximately 12 percent level next year. We feel that is entirely compatible with the risks that are involved and so forth. I think that is a fair level at this point.

Mr. **Glickman**. How about Ford-Garrett?

Mr. **Boppart**. I think it is perhaps illustrative to look outside of the specific contract itself and look at what we are doing that contributes to the success of the program. In reviewing where we have come so far, we find that among Garrett-Ford and our subcontractors, in the program to date for every dollar that the Government has spent on this program, we of our own money have put up another 70 cents in work—in either directly cost-sharing in the contract or other work that contributes directly to the accomplishment of this technology. We feel that that is a very, very significant level of contribution on the part of all of the teams, and it has been uniform among all of the participants in the team. We would expect that we will continue to do that in the future.

Mr. GLICKMAN. Would you be willing to basically indicate that in a letter to us?

Mr. BOPPART. Yes. We have, in fact, so indicated in our go-forward plan that we have submitted to NASA, and we would be happy to put it in a letter to you.

Mr. GLICKMAN. What would happen if, hypothetically, we ended up not with $12 million net to you each, but $10 million net to you each. I am wondering, just as a practical matter, whether you could go ahead and complete the project on the schedule that you talked to us about by putting up some additional money yourself.

Mr. BOPPART. I think that you are there within the range where the difference is one of risk and assurance of success. I believe that there is a quite reasonable prospect that the goals could be accomplished when you get down to the $10 million level. There is some point below that at which I do not think we can define very well today at which it would be my belief that the viability of a two contractor program at that level becomes somewhat questionable, and probably it would be advantageous to converge the programs.

Mr. GLICKMAN. You talked about the Japanese novel. What are they doing in ceramics? What are the Europeans doing in ceramics in terms of automobile related technology? A lot?

Mr. BOPPART. Yes. The greatly accelerating investment seems to be on the part of the Japanese. We find it difficult to get very good specific numbers because ceramics tends to be identified, when it is associated with a budgetary number, as one of several high-technology areas being pursued.

We did come across a recent Japanese security analysis which indicates an investment of over a billion yen—excuse me. I had better check my numbers. I get lost in yen. Over a hundred billion yen over a 10-year period for a group of programs, of which fine ceramics is the first priority.

Dr. MACPHERSON. We do know that the NGK Co. has produced a prototype engine. It is a very small engine, but it is almost entirely made of ceramics. Only the piston rings and the bearings, and I think there was one other part, were not made of ceramics.

We also know that the Kyoto Ceramic Co. has published pictures of a demonstration car in which the diesel engine makes use of significant parts made of ceramics.

Mr. BOPPART. That brings up an example I would like to tell you about which both bears on the level of Japanese subsidy of their industry and also what the consequences of a premature termination of Government sponsorship would be.

As we have shown you, one of the major parts in the engine is the rotary regenerator, this large thing that is made out of that material. In the process of our development so far we have obtained regenerator parts from two suppliers: Corning in this country and NGK in Japan. The cost, of course, of producing these things in very small quantities is very high. As a result, the parts that are supplied by Corning cost us about $15,000 a piece. The parts that NGK is supplying us, they charge us $2,500 a piece for.

I think this illustrates two things: (a) it illustrates the level of Japanese investment in getting onboard the technology. It also makes the point that if we are, in fact, required to do what we can with our own money, the requirements of economy are going to mean that we are going to buy our cores from NGK. When we do get to wherever we are going to go in the program, it is going to be NGK and not Corning who is thereby ready to go into production.

Mr. GLICKMAN. I am looking at the rotary models there, and I recall that when I was out at the Garrett facility last year I dropped one of those pieces and it broke. I am curious as to whether we can get to a point where a mechanic can pick one of those up without fear of destroying it. We are talking about something that will be practical.

Mr. HELMS. May I take a shot at that one?

Mr. GLICKMAN. I am not blaming Garrett for the fact it broke.

Mr. BOPPART. That is OK. We will not blame you, either.

Mr. GLICKMAN. It was my hands I think.

Mr. HELMS. I would call to your attention that in current automobiles there are many pieces of a similar nature. For example, every day we have a windshield that we look through, and I do not think you would dare drop that, either. I think the point you are making is well taken, that there is a training that is required to handle new material. However, I think that is easily accomplished in a realistic marketplace. Therefore, I think that is a point that is worth consideration, but I do not think it should be a detracting point because the payoff in the use of that kind of material is tremendous.

I would also suggest to you that we are looking at, rather than just the monolithic-type ceramics, those that may be reinforced in the future with fibers and other materials may give additional toughness to the material, maybe not the ductility we have in metals today, but I think these are still usable materials.

Dr. MACPHERSON. May I make a point?

Mr. GLICKMAN. Yes. Go ahead, Dr. Macpherson.

Dr. MACPHERSON. There is a training period required for these new materials. It is possible that this sort of component, which is a ceramic rotor for a turbocharger,[1] may well be in the market before we have a complete engine. Just as people had to learn progressively how to handle some of today's complicated pieces, we would expect to see a progressive training period in that aspect.

Mr. GLICKMAN. I might mention that I think you have pretty much sold me. I have a theory about what Government should and should not be doing. I opposed automotive content legislation because I thought that was an inappropriate role for Government. I think that your programs—and I happen to believe the Stirling program as well—while we may argue about their relative merits, are peanuts compared to what the Japanese and West Germans are doing. If we do not start eating those peanuts, they are going to be producing them all.

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[1] Dr. Macpherson showed the component to the subcommittee.

Mr. HELMS. The electronics ceramics industry is a good example of that.

Mr. GLICKMAN. That is right. I am thinking about some of the spinoff industries, not just in the automobile sector.

Mr. McCandless?

Mr. McCANDLESS. Thank you, Mr. Chairman.

I was wondering whether you dropped the NGK at $2,500 or the Corning one at $15,000. Would you care to comment on that?

Mr. GLICKMAN. Nobody went into great detail with me.

Mr. BOPPART. At risk of further embarrassment, and to answer Mr. Glickman's previous question on the handling, the fairly large number of parts that we bought from people and brought in are handled by the same people in our company that are in our receiving department and our stock rooms who handle everything else. We gave them some training. However, as a result of that, not one part has ever been broken in handling or receiving or storing in our company by us.

Mr. McCANDLESS. This could be interpreted as an unfavorable reaction to Congress. [Laughter.]

Mr. BOPPART. Only misinterpreted, sir.

Mr. McCANDLESS. I would like to go back in history, if I may, in the turbine programs in the past. Chrysler in its turbine program a number of years ago, and then recently the General Motors program in the truck configuration—the Chrysler program was dropped I guess because it was not something that they could apply on a commercial basis. I do not know exactly what happened to the GMC truck program.

What do we have here in the way of a program that is going to produce an end product that is going to be more marketable than these two predecessor programs that would justify taxpayers' investment?

Mr. HELMS. May I address that, please?

I have personally worked on the truck program that you have questioned. We have, on several occasions, gone through again these three marketplace criteria: Cost, performance, and reliability. The truck turbine that we worked on, we found the cost was in excess of what we thought the marketplace could withstand.

On each occasion that we have gone through our costing exercise, we find that the super alloy materials, the metals that are involved, are the cost-drivers, as we like to call them, that cause cost to be in excess of what is affordable in the marketplace.

It has been predominantly a cost consideration, but I have to add, in all fairness, it is also a performance consideration. We wanted the truck engine to be competitive with diesel, for example, in fuel economy. With the limitation that we had with the metals, we could not achieve either the fuel economy or the cost goals.

The thing that is new and exciting about ceramic materials is that we can now operate with these materials at much higher temperatures, which gives us the performance, and we can achieve these materials, we believe, in a production environment at costs much less than similar metal components would be.

Let me just illustrate that for you. That rotor priced in production quantities of 800,000 engines per year appears to come in at around $30 to $35 per rotor. That same rotor made of a super alloy would price out between $150 and $200. That is the kind of cost differential that is there and why the ceramics are so promising to us, and I think maybe makes the turbine practical.

Mr. BOPPART. If you did not make it out of ceramics, you couldn't operate it within several hundred degrees of the same temperature in metals.

Mr. HELMS. That is right.

Mr. BOPPART. Therefore, you would have a corresponding reduction in efficiency of the engine.

Mr. MCCANDLESS. I think you have answered that question more than adequately.

How do you plan to correct the deficiencies in the turbine acceleration?

Mr. HELMS. We have addressed that question very carefully. If I could ask you to look at a picture, figure No. 2, and it is not very apparent as you look at the picture, but there is a little black starter that sticks out toward the gentleman on the lefthand side. This is an example of cost-sharing by Delco-Remy. That is a special starter that is going to idle at all times. Most times you use a starter to get your engine going and you stop it. This starter runs at all times. The thing that is unique is that we have developed a technique for raising and lowering the starter brushes so it may act as a "boost" motor on the gasifier turbine.

The thing that has hurt the acceleration characteristic in the past has been how fast you could accelerate the gasifier rotor, this rotor you see here. We can use the battery power for a half to a second and a half and overcome this problem.

I did not bring with me our acceleration characteristics, but I can tell you that we are as good acceleration-wise with this starter giving a boost as we are in our conventional spark ignition engine or diesel engine, much better than a diesel, as a matter of fact, as good as the gasoline-type engine.

I would also suggest that if you look at either our engine or the Garrett engine, you also see variable guide vanes. By instantaneous movement of those vanes, again you can get almost instantaneous power through the increased air flow or, in the case of throttling, decreased flow. Between the two, the battery, the electric starter, and the guide vanes, we can achieve acceleration quite satisfactory in the automobile.

Mr. BOPPART. This is an area of subtle but significant difference in the characteristics of two engine configurations that we are developing. Therefore, I would like to add a comment.

We do not do the sort of thing Mr. Helms implied. On a perfectly simple, straightforward basis, our engine, which has the economy of giving you up to around 50 miles per gallon in a 3,000-pound car, will in fact accelerate that car from zero to 60 miles an hour in well under 10 seconds, which is very flashy performance by today's family passenger car standards. The average, moderately powered or economy-type passenger car nowadays takes in the range of 16 to 18 seconds to do that.

As a consequence, actually, of having sized these engines to have very good initial acceleration, they turn out to have fairly spectacular performance.

Do you want to comment on that?

Dr. MACPHERSON. May I just add one comment?

As the potential end-user, we have insisted all the way through that this aspect is covered in the design.

Mr. McCANDLESS. Even if you have such a potential mousetrap for the future—the Government did not get involved in the development with you for independent front suspension. It did not get involved with you in development of disc brakes and all of the other things that have taken place that make the automobile a more pleasurable car to ride in and a safer car than the predecessor generation.

What justification do you as industry have for saying to the Government now, "We want you to participate in program with us."?

Dr. MACPHERSON. May I take that very quickly, please?

The technologies you described, which are now in our current products, can be thought of as evolutionary technology. They have derived from the prior level in relatively progressive steps. Here we are talking about a step change in technology. We are talking about high-risk technology which is entirely dependent on being successful in the way we can design and manufacture complicated, or at least challenging, components in ceramics. It is literally a step change that we are looking for.

Mr. McCANDLESS. However, there was research and development on the part of Chrylser before they came out with independent front suspension in the 1934 Plymouth, and it was many years before their other vehicles came out with it. Certainly, the research and development cost of that had to be commensurate with the times and so forth.

You remember, Ford did not come out with any kind of independent suspension until 1949.

Dr. MACPHERSON. Yes. Perhaps I should just remind the committee of the very large amounts of money being spent by the industry on research and development. In terms of this technology, this project falls, because of its high risk and of its long-term nature, it does fall toward the bottom of the priority list we could give it in that expenditure.

Mr. McCANDLESS. Thank you, gentlemen.

Thank you, Mr. Chairman.

Mr. GLICKMAN. Mr. Carney?

Mr. CARNEY. Thank you.

Dr. Macpherson, Mr. Helms alluded to the difference between his engine and yours, having to do with his engine being able to fit the various types of transmissions, including the one that you have on your prototype engine. Would that transmission be applicable to other types of engines?

Dr. MACPHERSON. Yes.

In the Ford-Garrett powertrain we have emphasized all the way through that we are thinking of this advanced concept of a continuously variable transmission. I should tell the committee that we expect such transmissions to be in the marketplace for use with conventional engines well ahead of the time that they would be needed for this engine.

Mr. CARNEY. Thank you.

Mr. BOPPART. If I may, I would just like to emphasize one point there.

I do not want to leave the impression that our engine requires the continuously variable transmission. Our base-line drive train, on which our original 42.8-miles-per-gallon figure is based, is a modification of a fairly conventional, four-speed, automatic transmission. The CVT gives an added benefit, but it is not a requirement to make it a competitive device.

Mr. CARNEY. You will have to beg my pardon, but I was called out of the room on three occasions, and I apologize for that. Therefore, I might be asking questions that have been asked before.

How much has each company—I know we have a joint venture going here, but how much resource money have Ford and Garrett put into this program?

Mr. BOPPART. In the submittal that we made to NASA in the go-forward program, we have identified the contributions that Ford, Garrett, and our suppliers have made in various forms toward the conduct of this program. A simple way of putting it is that for every $1 that the Government has invested in this program, we, our team, have together put up another 70 cents.

Mr. CARNEY. You are not talking about in all instances real dollars but associated costs for what you might put in it?

Mr. BOPPART. No, I am talking about real dollars. They are not all dollars that appear on this contract.

Mr. CARNEY. Right. You are talking about inkind types of things.

Mr. BOPPART. That are contributory to this technology, yes.

Mr. CARNEY. Mr. Helms?

Mr. HELMS. I have not cataloged the costs quite the way John has, but I suggest to you that our contribution would be equal in magnitude.

I think I mentioned earlier that we had developed a rotor larger than this, one that would be adequate in size for a truck. That was done on our money. The money that are being spent with GTE Laboratories to develop a silicate nitride technology have been with General Motors money. There are many, many instances like this, and I suspect we could also show somewhere between 50 cents and 70 cents on the dollar as a contribution we make.

One of the things that is hard to assess is what value do you place on all of the facilities, the special instrumentation, and other things that are standard operating equipment with us that are used to support these programs. It is quite a significant dollar level.

Mr. CARNEY. Let me ask the question this way, then, in reply to that: If Detroit Diesel Allison decided to get out of the business of continuing this program and the Federal Government was willing to continue to fund the program, how long would the line be for someone else to pick it up?

Mr. HELMS. What was the first part of your assumption there?

Mr. CARNEY. I am saying if you decided for some reason not to continue the program and NASA-DOE continued to fund it at the current levels that we are, how long would the line be for other companies to pick up the program? In other words, how many other companies would lend us their assets, their buildings, and that type of thing?

Mr. HELMS. Well, I am sure there would be others. Let me answer your question that way. I do not know how many. I am sure there would be others.

Mr. BOPPART. I do want to make clear that I am not counting use of assets in the number that I quoted you.

Mr. CARNEY. On that note, the chairman asked me if I would adjourn the committee. If my colleague from California——

Mr. MCCANDLESS. I would like to hit them with one more.

Mr. CARNEY. Sure.

Mr. MCCANDLESS. We have been conspicuously silent by the noise that generally is attributable to a turbine operation. Since we are talking in a rather informal manner, how do you plan to solve that?

Mr. HELMS. The noise that the ear perceives is very important. You will note that most of the noise in a turbine is very high frequency, high-pitched noise.

It so happens that both our concepts use a regenerator which is quite effective as a noise suppressor for much of the noise that is generated by the turbine. Further, the noise that tends to come out of the front of the engine, which is the compressor end of the engine, again is an extremely high-frequency noise, very little of it perceived by the human ear.

I believe that that noise that does come out will not be a disturbing noise in the classical sense of thinking of noise levels and so forth.

We have run, for example, at General Motors Research Center cars with turbine engines with the kind of compressors we discussed here. That noise is a very low-level noise and a very nondisturbing noise or perceived noise to the human ear.

Mr. MCCANDLESS. Let's take one of the engines, either Ford or General Motors, the conventional combustion engine and put a stratified charge and do everything that technology has currently available for that engine within the framework of a salable end product at the retail level. The tailpipe emissions of that product versus what you have now in the way of a ceramic rotary-type engine—where are we in terms of grams per mile and the other types of measurements?

Dr. MACPHERSON. I can perhaps handle that in a somewhat roundabout way.

Mr. MCCANDLESS. I am from California and we have a problem, and I think you know what the problem is. It is a 50-State problem, they call it.

Dr. MACPHERSON. Essentially, the sort of combustion system we are using in the gas turbine can always be better than the emissions you get out of the normal reciprocating engine. Combustion can be handled in a much more controllable fashion.

Mr. MCCANDLESS. Because of the temperature?

Dr. MACPHERSON. No, because the combustion is steady.

Mr. BOPPART. It is continuous.

Dr. **Macpherson.** It is a continuous combustion. It is possible to give generous amounts of air to the flame, and it is possible to control the emissions.

When we think of the conventional reciprocating engine, for a spark system to be successful, we have to aim at certain chemical proportions so that the spark will ignite the mixture. That tends to give higher levels of emission than in the sort of combustion system we have here. Therefore, in principle, this should be a lower pollution engine.

Mr. **McCandless.** Would you venture a percentage?

Dr. **Macpherson.** No, I wouldn't want to venture a percentage at this stage in the development. That will emerge as we go through the program.

Mr. **Boppart.** One thing that has changed during the program is that in the original concept both DDA and the Garrett-Ford team used variable geometry moving parts in the combuster as a way to meet emission standards. In both of our cases—I believe I am correct—in the progress that we have made to date we have found that we are able fairly readily to beat any of the statutory requirements, and I think Mr. Helms referred to that in one of his figures, without going to variable geometry. Therefore, the control of emissions appears to be very well in hand.

The other point I guess we probably ought to make, and I know you are very familiar with it, is the issue of particulate emission, which is a major concern with diesels. Of course, the gas turbine does not have a particulate emission problem at all, even using diesel fuel.

Mr. **Helms.** That was the point I was going to make. If you look at our figure 5, you can see, for example, the NO_x that is shown there is 0.1, and that is in grams per kilogram of fuel burned.

To the best of my knowledge, that far exceeds the standards, and the diesel, of course, would have a great deal of difficulty meeting the dotted line on that figure. The characteristic products of combustion from a turbine, which is a continuous burning cycle, are radically different from those of an interrupted burning situation.

I concur with what Ian said there.

Mr. **McCandless.** I have one final quickie.

Going back to the scenario that we used earlier, you have your conventional engine option. You have then a turbine option in the same vehicle. What would you judge to be the price differential?

Mr. **Helms.** Would you like to respond to that. Again, I will go first or second.

Dr. **Macpherson.** Let me try to help on that, Mr. McCandless.

Mr. **McCandless.** Remember our ancestry now when you come up with a figure.

Dr. **Macpherson.** Oh, yes, absolutely. I can explain why a Scotsman's interested.

We think that ceramics potentially do offer relatively low-cost components. We do think that these engines are relatively simple in terms of the number of parts inside them.

We must also recognize that by the time we are speaking of some of the engines I have shown in my figure 16, turbocharged, compound diesels, they are going to be very expensive units.

If we, therefore, extrapolate the sort of conventional technology that will be coming along by 1990, say, that will progressively be more complicated and more expensive.

I have a great expectation or hope that this could be a fully competitive car unit.

Mr. **McCandless**. We are not building a mousetrap that no one is going to be able to sell?

Dr. **Macpherson**. I do not believe that.

Mr. **Helms**. I do not believe that.

We have run the truck turbine in buses, trucks, boats, and so forth, and have accumulated more than 4 million miles in that kind of application and found the users to adapt to the turbine very readily with very few problems.

I think this is one of the beauties of the turbine—its replaceability now. It is going to be costly to convert—to produce in the turbine in production quantities. However, once that expense is made, the turbine is readily adaptable in the marketplace.

Mr. **McCandless**. Thank you.

Mr. **Carney**. Thank you, Mr. McCandless.

Before we adjourn this meeting, I would simply like to say for the benefit of the committee members that our next meeting is March 3 at 10 a.m. It will be the markup on the NASA and DOE programs that this subcommittee has responsibility for.

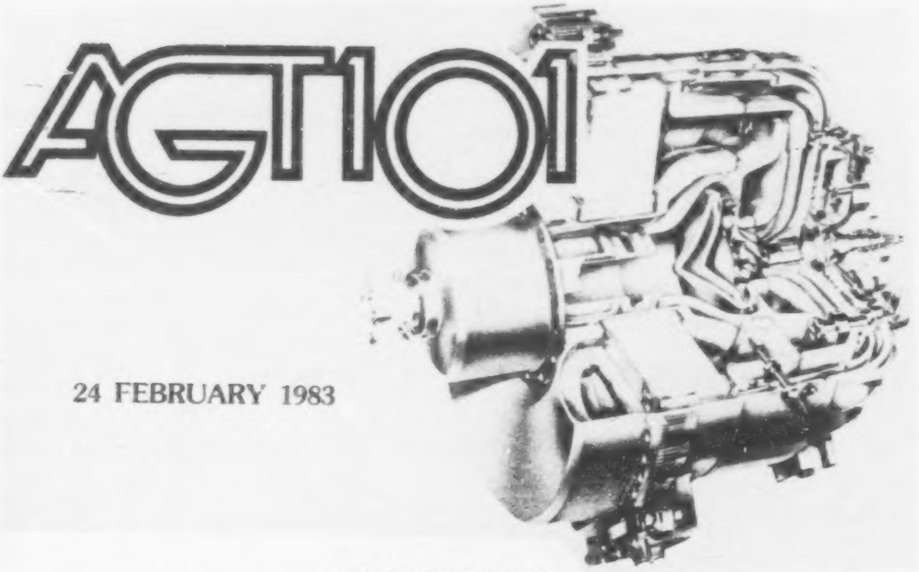
I will adjourn the meeting.

[Whereupon, at 4:02 p.m., the hearing adjourned.]

[The prepared statements of Dr. Boppart, Dr. Macpherson, and Mr. Helms follow:]

TESTIMONY BEFORE
THE SUBCOMMITTEE ON TRANSPORTATION
AVIATION AND MATERIALS
OF THE
COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

PROGRESS REPORT GARRETT/FORD AUTOMOTIVE GAS TURBINE PROJECT



24 FEBRUARY 1983

JOHN BOPPART
VICE PRESIDENT, ENGINEERING
GARRETT TURBINE ENGINE COMPANY

DR. IAN MACPHERSON
DIRECTOR, POWERTRAIN RESEARCH
FORD MOTOR COMPANY

MP-85633

GARRETT TURBINE ENGINE COMPANY
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

JOHN BOPPART

VICE PRESIDENT, ENGINEERING

Education

B.S. in Mechanical Engineering, California Institute of Technology, 1952

M.S. in Mechanical Engineering, California Institute of Technology, 1953

Work History

1957 to Date: Garrett Turbine Engine Company

- Vice President, Engineering
- Director of Engineering
- Assistant Director of Engineering, Power Systems
- Assistant Director of Engineering, Pneumatic Systems
- Chief of Pneumatic Control Systems
- Senior Project Engineer, Pneumatic Actuation Systems
- Project Engineer, Pneumatic Control Systems
- Assistant Project Engineer, Advanced Power Generation Systems
- Senior Systems Engineer, Systems Support Group

1953 to 1957: AiResearch Manufacturing Company of Los Angeles

- Preliminary Design Engineer
- On loan to Advanced Design Group, ANP Project, Oak Ridge National Laboratory (1956)

Responsibility/Experience

Mr. Boppart currently is responsible for all engineering activities for Garrett Turbine Engine Company.

As Assistant Director of Engineering, Mr. Boppart was responsible for all engineering activities associated with all AiResearch Power Systems products. Prior to this, he was similarly responsible for all AiResearch Pneumatic Systems products.

All engineering functions involving the Power Systems and Pneumatic Systems product lines were under his direction including engineering estimates through design, development, and qualification, and the production liaison activities during the follow-on production deliveries.

Mr. Boppart's prior experience also includes work in various capacities of engineering on pneumatic valves and controls, air motor pneumatic actuation systems, missile and space control valves, space power systems, gas turbine auxiliary power systems, and aerospace environmental control systems.

IAN MACPHERSON

Director — Powertrain Research Laboratory
Ford Motor Company

Education

B.S. in Physics — University of Manchester, England, 1951

M.S. — Cosmic Ray Physics

PhD. — University of Manchester, England, 1952/1955

Work History

1971 to Date: Ford Motor Company

- Director, Powertrain Research Laboratory
- Chief Engine Engineer, Truck Operations, Ford of Europe
- Executive Engineer, Truck Operations, Ford of Europe

1955 to 1971: Rolls Royce Ltd., Aero-Division, England

- Assistant Chief Research Engineer, Combustion and Turbine Systems
- Head of Advanced Research Laboratory
- Section Head, Gas Dynamics Research
- Project Engineer, Submarine Nuclear Reactor Project
- Project Engineer, Combustion Research

Responsibility/Experience

Dr. Macpherson is responsible for all activities within the Powertrain Research Laboratory of the Ford Motor Company, with particular emphasis on future engines and transmissions of relevance to automotive and tractor systems, including alternative fuels.

As Chief Engine Engineer, Truck Operations, Ford of Europe, he was responsible for diesel engine design and development for commercial vehicles. This covered advanced engineering, development of new products and close liaison with production and field activities, including industrial engines.

Work at Rolls Royce covered a span of technologies, ranging from nuclear reactors for submarine propulsion; gas dynamics and combustion at hypersonic conditions; materials and basic physics research; to line responsibility for the combustion and turbine technology embodied in all Rolls Royce gas turbines.

GARRETT TURBINE ENGINE COMPANY
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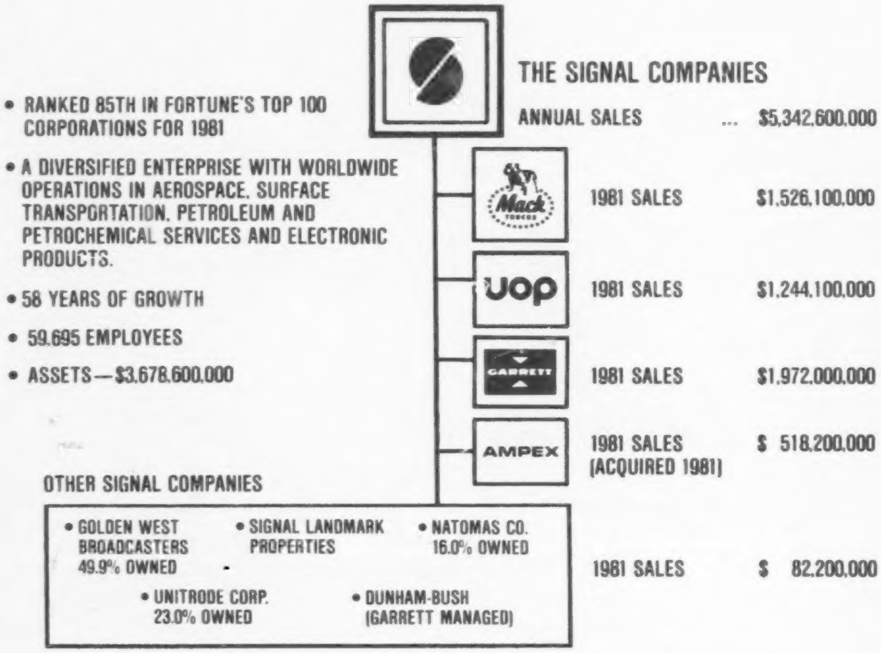
PHOENIX, ARIZONA

Mr. Chairman and members of the subcommittee, my name is John Boppart. I am Vice President of Engineering for Garrett Turbine Engine Company, a division of the Garrett Corporation. I would like to introduce Dr. Ian Macpherson, Director, Powertrain Research of Ford Motor Company; Dr. Macpherson will join me today in presenting this testimony.

The Garrett Corporation is a member of the Signal Companies. Signal is well known as a supplier to the needs of the transportation industry because of its activity by Garrett in gas turbines and turbochargers, and in large vehicles (Figure 1).

Garrett and Ford Motor Company are working together to develop high-risk, long-range technology for advanced automotive gas turbines for future automotive and other power plants. We are currently under contract to the Department of Energy and NASA. Garrett is the prime contractor with major support from Ford.



THE SIGNAL COMPANIES
ANNUAL SALES ... $5,342,600,000

- RANKED 85TH IN FORTUNE'S TOP 100 CORPORATIONS FOR 1981
- A DIVERSIFIED ENTERPRISE WITH WORLDWIDE OPERATIONS IN AEROSPACE, SURFACE TRANSPORTATION, PETROLEUM AND PETROCHEMICAL SERVICES AND ELECTRONIC PRODUCTS.
- 58 YEARS OF GROWTH
- 59,695 EMPLOYEES
- ASSETS—$3,678,600,000

Mack	1981 SALES	$1,526,100,000
UOP	1981 SALES	$1,244,100,000
GARRETT	1981 SALES	$1,972,000,000
AMPEX	1981 SALES (ACQUIRED 1981)	$ 518,200,000
OTHER SIGNAL COMPANIES	1981 SALES	$ 82,200,000

OTHER SIGNAL COMPANIES
- GOLDEN WEST BROADCASTERS 49.9% OWNED
- SIGNAL LANDMARK PROPERTIES
- NATOMAS CO. 16.0% OWNED
- UNITRODE CORP. 23.0% OWNED
- DUNHAM-BUSH (GARRETT MANAGED)

Figure 1. The Signal Companies.

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This is the third consecutive year that the Garrett/Ford team has provided testimony to this committee. In the past, we have emphasized the benefits of the program to the nation. In today's testimony, I want to focus on the significant progress we have been making and on our go-forward plan.

Let me first say that the technology evolving from the AGT program continues to be of critical importance. In October 1982, Dr. George A. Keyworth II, Science Advisor to the President and Director of the Office of Science and Technology Policy, addressed the New York Society of Security Analysts. He opened his talk with these words, "Isn't it incredible that the United States has the greatest science enterprise the world has ever known — yet we watch, seemingly powerless, as foreign industries turn our science and technology into products that capture our own markets? Something is obviously wrong."

Our auto industry remains under strong foreign competition and our economy still suffers as a result. Many foreign governments are heavily supporting research and advanced technology engines. If we are to regain this ground and improve our competitive posture, then our government should continue to support our industry during these trying times.

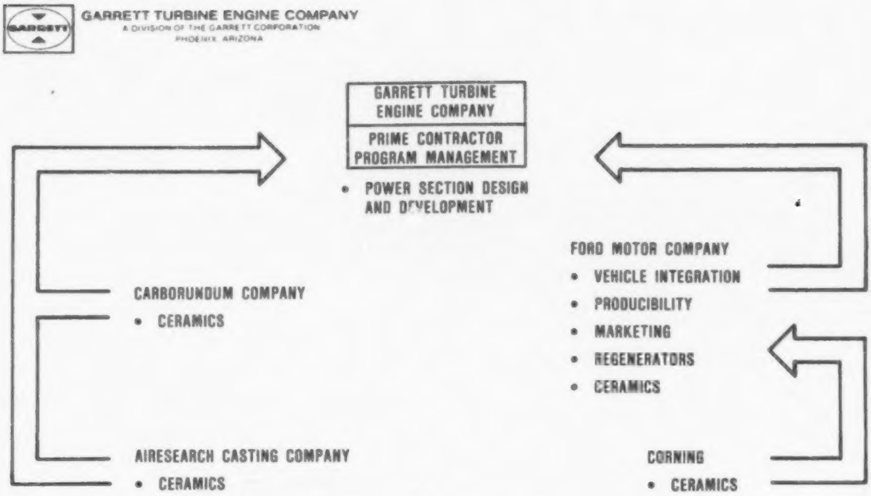
The automotive Advanced Gas Turbine Program was originally established pursuant to the "Automotive Propulsion Research & Development Act of 1978." This committee was instrumental in establishing that legislation. Since inception on the first day of October 1979, the program has been restructured as a long-range, high-risk technology program to develop an advanced technology base applicable to a competitive automobile gas turbine engine.

Garrett is a world leader in small gas turbine and turbocharger technology and products for a variety of aerospace, transportation and industrial applications. We bring to this program our expertise in advanced gas turbine development, including ceramics; Ford brings their automotive expertise and an extensive ceramics capability.

In addition to Ford, we have other major subcontractors in this program such as Carborundum Company, Corning Glass Company, and the AiResearch Casting Company (a Garrett Division). These are depicted on Figure 2. All these companies are conducting research and development of ceramic parts for the AGT program. Other subcontractors and vendors are located around the country as shown in Figure 3.

As you will recall, the AGT101 utilizes ceramic components; ceramics are under intensive development by foreign competition as well. The reason for this interest merits a brief review.

Ceramics are essentially nonmetallic, inorganic materials. Ceramics can replace many of the strategic materials currently being imported from foreign sources for use in manufacturing today's engines. Ceramic elements are readily available within the United


GARRETT TURBINE ENGINE COMPANY
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GARRETT TURBINE ENGINE COMPANY
PRIME CONTRACTOR PROGRAM MANAGEMENT
• POWER SECTION DESIGN AND DEVELOPMENT
FORD MOTOR COMPANY
• VEHICLE INTEGRATION
• PRODUCIBILITY
• MARKETING
• REGENERATORS
• CERAMICS
CARBORUNDUM COMPANY
• CERAMICS
AIRESEARCH CASTING COMPANY
• CERAMICS
CORNING
• CERAMICS

Figure 2. Garrett/Ford AGT101 Program Team.

States and other friendly nations. As you can see on Figure 4, silicon and nitrogen are elemental constituents of ceramics. There is an inexhaustible supply of these elements available at low cost. Many of the strategic materials used in gas turbine engines are being depleted and would not be available in automotive production quantities. In any event, cost of these strategic materials is not competitive for automotive application. A quantitative comparison with ceramics is shown in Figure 5.

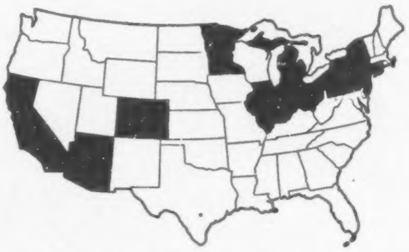


Figure 3. AGT101 Subcontractors and Suppliers.

Now I would like to discuss the significant progress the AGT101 team has made. As you will recall, the original program objective was to develop an advanced gas turbine that would demonstrate 42.8 miles per gallon over the metro-highway (combined federal) driving cycle (mostly city) in a 3000-pound car by the end of 1985. A variety of fuels were to be used and emissions levels of that period were to be met. As we have already stated, the program was reoriented to one that would develop an advanced technology base applicable to a competitive automobile gas turbine engine. As a result, the program has been restructured to develop the advanced gas turbine technology elements that are evaluated in the engine (now a test bed for the evaluation).

As you may recall, the AGT101 (Figure 6) is a 100-horsepower engine that operates at speeds to 100,000 RPM and temperatures as high as 2500°F. This high-temperature operation is made possible by the use of uncooled ceramic components.

EARTH'S CRUST	PERCENT
OXYGEN	50.0
SILICON*	25.7 **
ALUMINUM	7.3
IRON	4.2
CALCIUM	3.2
SODIUM	2.4
POTASSIUM	2.3
MAGNESIUM	2.2
HYDROGEN	0.95
TITANIUM	0.43
CHLORINE	0.21
CARBON*	0.19
PHOSPHORUS	0.11
SULFUR	0.11

ATMOSPHERE	PERCENT
NITROGEN*	77***
OXYGEN	22

*ELEMENTAL CONSTITUENTS OF CERAMICS SiC, Si_3N_4

**EQUIVALENT TO ABOUT 25.7 MILLION TONS/PERSON

***EQUIVALENT TO ABOUT 1.1 MILLION TONS/PERSON

Figure 4. Abundant Ceramic Elements.

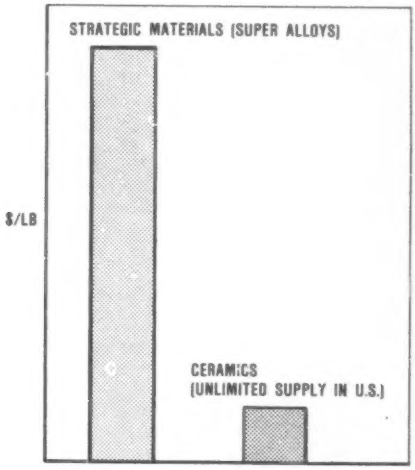


Figure 5. Ceramics Versus Strategic Materials.

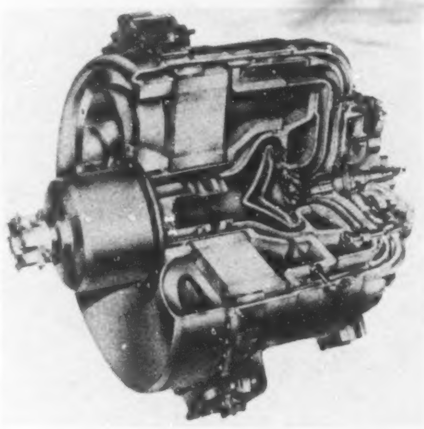


Figure 6. AGT101 Power Section.

Note the simple rotating assembly, comprising a single aluminum compressor wheel and a single ceramic turbine wheel supported by a gas-lubricated bearing (requiring no lubrication in the engine). An oil-lubricated bearing is located in the gearbox where transmission oil is available.

A ceramic rotating regenerator is used to recover waste heat that would otherwise be lost. This increases engine efficiency, which improves fuel economy. Note that the ceramic parts are symmetrical in shape to allow ease of fabrication, reduction of stresses, and eventual low cost. Thus, a major effort is directed at developing ceramic materials that surpass presently available technology. Our ceramic suppliers have provided the components shown in Figure 7 for test in our rigs prior to installation in the engine.

Before we can evaluate the ceramics and other technologies in the engine test beds, we develop the components or subassemblies in test rigs. As you may see from Figure 8, outstanding progress has been demonstrated in our aerodynamic, thermodynamic, and endurance test rigs. Please note that over 3900 hours have been accumulated in this high technology development effort. In addition to

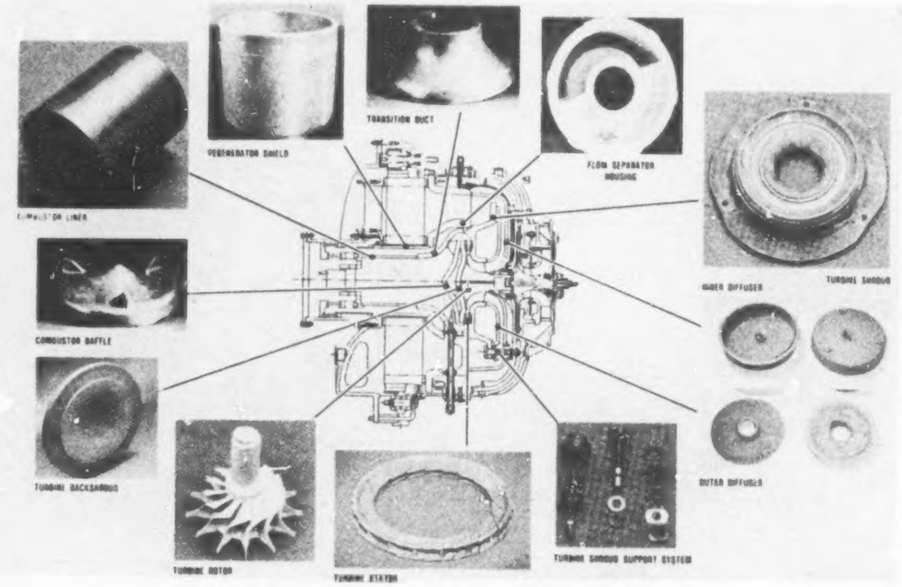


Figure 7. AGT101 Ceramic Parts.

GARRETT TURBINE ENGINE COMPANY
A DIVISION OF THE GARRETT CORPORATION
PHOENIX ARIZONA

RIG	ACCUMULATED HOURS THROUGH 1/31/83
COMPRESSOR	
IGV FLOW RIG	42
COMPRESSOR RIG	57
TURBINE COLD FLOW TEST RIG	122
COMBUSTOR	
AUTO IGNITION RIG	68
ELEMENT RIG	
MAIN COMBUSTOR RIG	39
REGENERATOR	
COLD FLOW REGENERATOR RIG	102
HOT FLOW REGENERATOR RIG	55
FORD SEAL WEAR RIG	2020
FORD STATIC SEAL RIG	1075
ROTOR DYNAMICS	
ROTOR DYNAMICS RIG	129
HOT FOIL BEARING RIG	11
FOIL BEARING TEST RIG	177
CERAMICS	
THERMAL SCREENING	7
STRUCTURES RIG	9
TOTAL	3923

Figure 8. AGT101 Component Test Experience.

ceramics; high performance aerodynamics, low emissions, multi-fuel combustion, highly effective low leakage heat recovery (regenerator), rotor stability at high speeds (100,000 RPM), and a gas-lubricated bearing (foil) are outputs of this technology development.

We will talk more about the ceramics work in a moment; but first, a brief review of the engine test bed evolution. The engine (or power section) development testing started in mid-1981 with a 1600°F operating temperature, and a metallic configuration utilizing metal components instead of ceramics (except for the regenerator core). The reason for starting at a lower operating temperature is to allow checkout of the engine test bed while the ceramics and other long-lead technologies are being developed. As the technologies evolve, they are integrated into the engine as shown in Figure 9. The operating temperatures increase until the ultimate 2500°F is achieved with all ceramic components in place.

To date, three engine test beds have been tested to 100,000 RPM and have accumulated

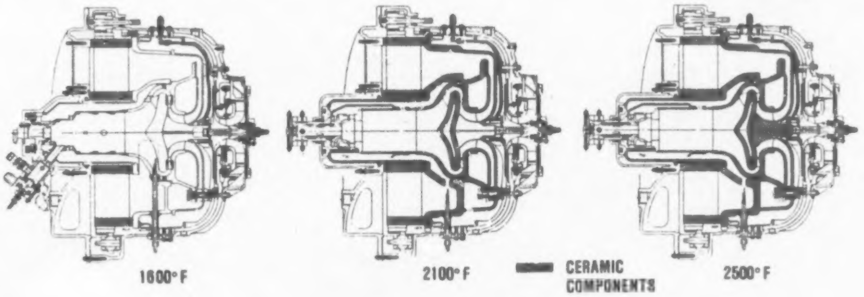


Figure 9. AGT101 Engine Evolution.

about 127 hours of operation. One of these engines (Figure 10) is being readied as a solar powered powerplant test bed to provide electrical power while operating on solar energy, or fossil fuels, or a combination of the two. The solar unit is being co-sponsored with another DOE/NASA/Jet Propulsion Laboratory program.

Now I will review our ceramic progress. When the program started, the ceramic contractors were not sure how the bladed turbine rotor and several of the large, thick ceramic parts should be fabricated; new breakthroughs in ceramic development were required. However, by working closely together in a give-and-take atmosphere, many breakthroughs have been made and all parts now have been fabricated and tested. Most of the more difficult components have been made by more than one contractor, by different methods, and in some cases, of different ceramic materials. All ceramic structural parts have been successfully tested individually to 2100°F in test rigs to simulate operating environments and to screen out poor quality parts. When this is accomplished, the structural parts are then assembled into a ceramic module (Figure 11) for test in the ceramic structures test rig (Figure 12). This rig simulates an engine environment as closely as possible, but does not incorporate a rotating assembly. This test is a further screening operation to eliminate parts that could fail in the engine test bed

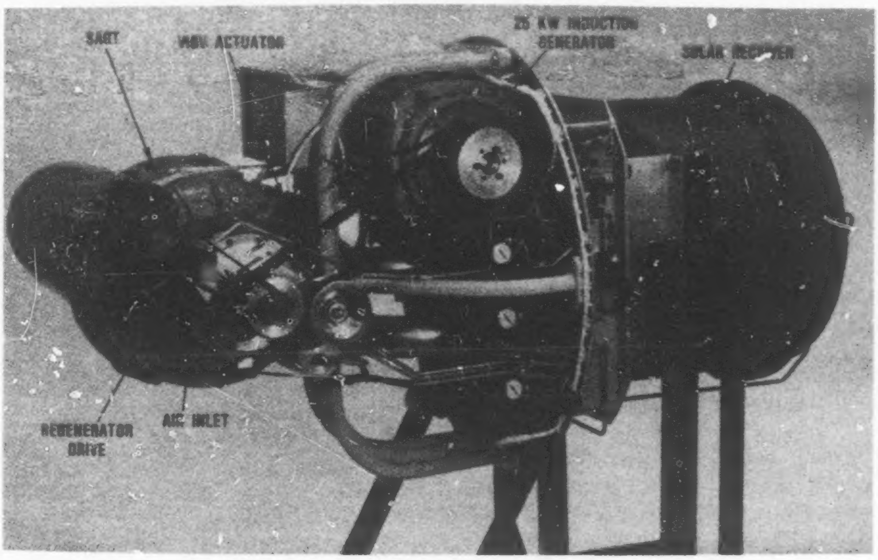


Figure 10. SAGT-1A Brayton Power Conversion Assembly.

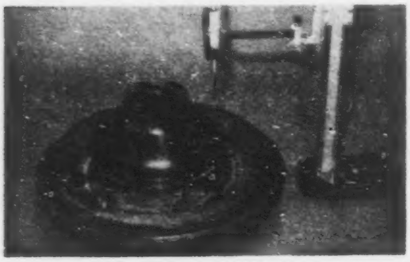


Figure 11. Ceramic Module.

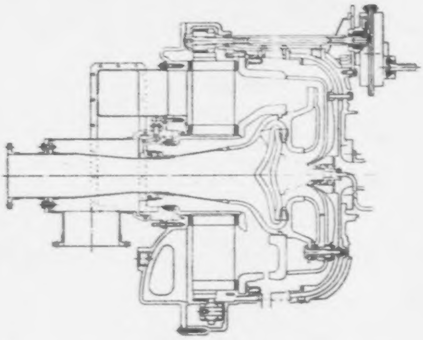


Figure 12. AGT101 Ceramic Structures Test Rig.

A successful test of a complete ceramic module was accomplished to 1600°F in 1982 and is scheduled for 2000°F in the near future. Simulated engine starts and stops were accomplished.

Let me pause here to emphasize that ceramics must be developed in the manner described above in order to successfully, and with minimum expense and time, develop them for applications such as a gas turbine. Ceramics are in the early stages of development, as metals were many years ago and must be developed in a step-by-step cooperative approach. To be successful, the ceramic parts must be evaluated in the environments in which they will be operating.

During the process of bringing ceramic components to the current status, a number of design changes have evolved. We have learned that ceramic parts tend to "stick together" at the elevated temperatures and pressures experienced in a gas turbine. These problems are being addressed and solved.

The ceramic turbine is an especially tough challenge. Initially, four ceramic contractors were asked to make bladeless rotors to see if the ceramics could meet the speed and strength design requirements. Ford and AiResearch Casting Company were successful with the bladeless configurations, and now are developing bladed rotors. The two approaches are shown in Figure 13.

The first ceramic bladed rotors have been successfully cold spin tested and now are undergoing hot spin testing under simulated

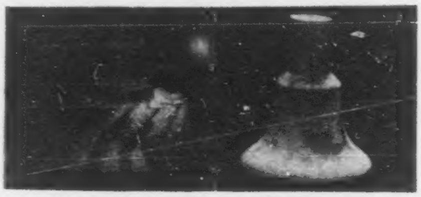


Figure 13. AGT101 Turbine Rotor Approach.

engine operating conditions in a test rig. Test rig spinning imposes stresses on the ceramic rotors that simulate the stresses imposed by the engine. These spin tests have been devised as a method of screening out turbines that are defective because of material flaws, before engine testing, so that confidence of success is enhanced. Successful completion of these tests will qualify the ceramic turbine for initial engine testing.

The successes we have accomplished thus far are very encouraging. However, these successes represent only the beginning in the evolution of ceramics. Our testing has been minimal and the quantity of components limited; both must be greatly increased to prove that the technology is ready for industry to carry it forward to production.

The AGT101 program accomplishments have been made during a period of budget reductions, constraints, and uncertainties. When the program was reoriented in 1981 and funding reductions took place, a go-forward program was recommended to this committee. That program has been followed since that time and is consistent with the program schedule shown in Figure 14. The long-range, high-risk technology elements of the power section are being brought forward. Component testing, followed by engine test bed evaluation, is

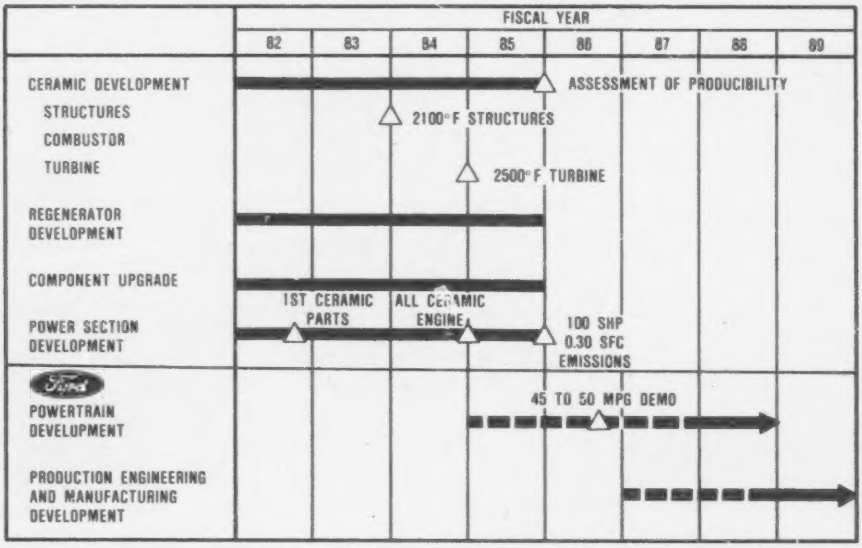


Figure 14. Restructured AGT101 Program.

leading to a late 1985 demonstration of AGT101 power, performance, emissions and multi-fuel capabilities in an engine dynomometer. The ceramic parts will have been tested in the engine by that time and initial judgements as to their suitability for mass production in the early 1990's will have been made.

Ford, as well as other automotive companies, has new transmissions under development that will further improve the AGT101 powertrain fuel economy. The original goal was 42.8 mpg in a 3000-pound car; however, these new transmissions provide the potential of increasing this fuel economy goal to 45-50 mpg for vehicles that we expect could emerge from the pilot production phase beyond this technology program.

We have been strong advocates that AGT101 program goals should be accomplished by the end of 1985. Funding has not been consistent since our recommendation in 1981. We estimated that $32-40 million would be required from the government in FYs 82 through 85. This level of funding has not been available in FY82 and early FY83. It appears that unless $12 million is provided both in FY84 and FY85, the program end date will need to be extended into FY86 or else the end objectives will need to be compromised.

Before concluding, I would like to remind you that the AGT101 technology is applicable to many other future applications. For example, the AGT101 is being evaluated as a dispersed solar thermal generator set; this approach could reduce the country's demand for fossil fuel. Multi-fueled generator sets for potential military use are being considered, as are tractors, construction equipment, and trucks, which are all candidates for AGT101 powerplants. Aircraft powerplants and auxiliary power units also are potential applications. Other technology spin-off potentials involve adiabatic diesel engines, diesel particulate traps, turbochargers, cutting tools and reduced friction components.

CONCLUSIONS AND RECOMMENDATIONS

The current AGT101 program is an advanced long-range, high-risk powerplant technology program that is consistent with administration guidelines for government support. The technology being developed will aid in reducing our country's energy consumption and dependence on foreign oil. The program also provides the technology base to potentially reduce our dependence on strategic materials; these materials are being depleted worldwide, are expensive and many are supplied by foreign nations. The foreign government subsidized competition is keen and must not be allowed to further degrade our industrial marketshare and balance of trade.

The AGT101 is a test bed for technology advancement in the areas of ceramics, multi-fuel capability, heat recovery, and other performance improvements. Ceramics offer many advantages for future powerplants, such as lightweight, low cost constituents available within our country, and from improved engine efficiency. Based on independent studies, Ford has concluded that the ceramic gas turbine is among the most promising potential future automotive powerplant as Dr. Macpherson will discuss with you in a moment.

We recommend that the AGT101 program be completed by the conclusion of 1985 and that adequate funds be provided in FY84 and 85 to allow current milestones to be accomplished. That would allow industry to carry the technologies forward toward production in a timely manner. As Dr. Keyworth said in the talk previously referenced, "This Administration's science policy is directly concerned with strengthening the world market position of our high technology industries."

Thank you for the opportunity to address the committee once again. We are proud of what we have done, and with your help we can do a lot more. Dr. Macpherson will now make his statement.

Mr. Chairman and members of the subcommittee, my name is Ian Macpherson and I am the Director of the Powertrain Research Laboratory of the Ford Motor Company.

My close involvement with the AGT program only started in November last year when I succeeded Mr. Richard Ronzi who testified before this committee about twelve months ago. My previous experience in industry includes several years working on gas turbines for aircraft propulsion. With this background, I can say, even from my brief period on this program, that the technical content and eventual commercial application of what we are endeavoring to accomplish is a source of excitement and enthusiasm for me and a potential product opportunity for Ford.

In following John Boppart's remarks, I should like to bring the subcommittee's attention to some aspects that are of particular interest to the Ford Motor Company. My remarks will fall naturally under the following headings:

- The powertrain concept based on the AGT, fuel utilization and economy, as this relates to future powertrains for automotive products.
- Spin-off from the ceramics technology.
- The time scale of possible applications.

POWERTRAIN CONCEPT

In evaluating the powertrain concept, we need to remember that the 100 HP produced by the rotor spinning at 100,000 rpm has to be converted to power at the road wheels. The subcommittee may recall that the transmission or gearbox we have in mind is the continuously variable transmission. Because of restraints in funding, our initial plans to work on such systems for the AGT101 have been postponed but, nonetheless, I can show you the schematic arrangement of what we have in mind as in Figure 15.

The key point is that by allowing the overall gear ratio to vary in a continuous, smooth manner, we can arrange for the gas turbine to work close to its optimum operating conditions most of the time, without regard to vehicle speed, thus optimizing the fuel consumption of the total system. A study of the performance of the AGT concept, compared to other advanced prime movers was published by Ford a few months ago and the results are summarized in Figure 16. It will be no surprise to see that we believe the AGT has the potential, when we can achieve the target operating condition, to have an outstanding capability for fuel efficient operation. We should remember when thinking of this that the AGT has the additional desirable features of:

- Tolerance to variations in fuel type, including alternatives to gasoline
- Low combustion noise
- Good emission control

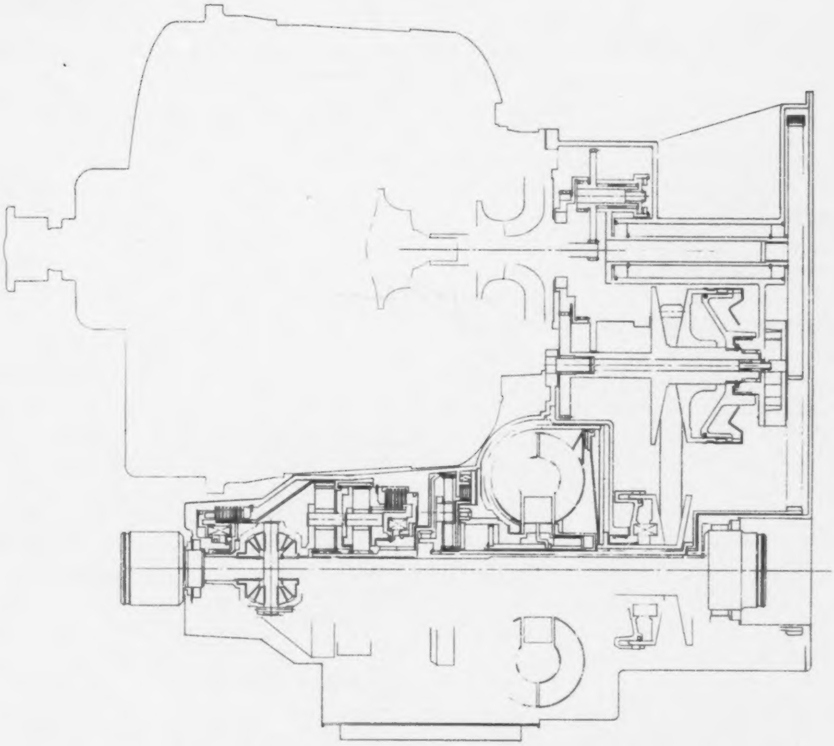


Figure 15. Preliminary Continuously Variable Transmission (CVT) Concept.

SPIN-OFF FROM CERAMICS TECHNOLOGY

John Boppart has explained how progress has been made on the technology that lies at the very heart of the AGT — the technology of ceramic materials. I need only to add a few words about the following aspects to reinforce what he has said:

- The AGT is totally dependent on success in this challenging field to achieve the high operating temperatures required for efficiency.
- We, at Ford, see ceramics technology as one that is now emerging into an important position in prime movers after many prior years of painstaking and slow

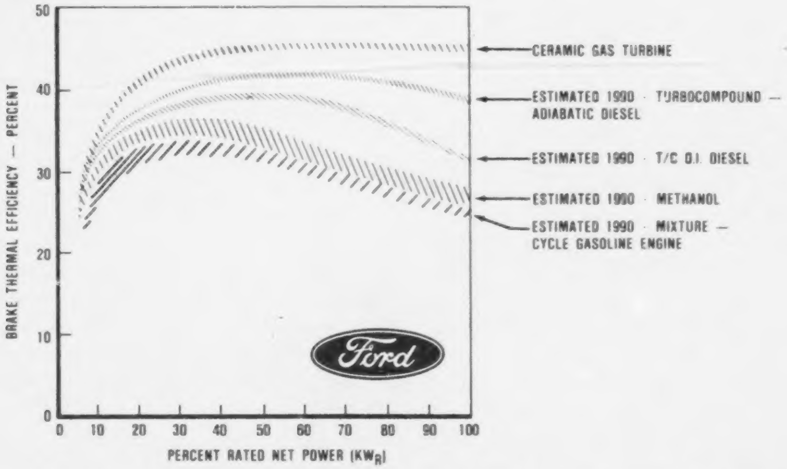


Figure 16. Ford Comparison of 1990+ Estimated Engine Efficiency Characteristics.

progress. We have made great strides in the past 12 months in achieving, under laboratory conditions of course, a high degree of consistency and material capability for the most difficult component, the turbine rotor shown in Figure 17. This and other progress in the program add to our confidence that application to other prime movers is not too far ahead. Members of this subcommittee will not need to be told of the growth of activity in ceramics technology in Japan as doubtless you will remember articles in the technical press on the totally ceramic engine produced as a prototype for experimental work in that country. We can safely assume that similar activity is underway in other countries endeavoring to keep at the forefront of leading technologies.

- The spin-off of technology from this program is not just related to prime movers alone. Ford has already announced publically the development of ceramic tips for cutting tools and we expect that other similar avenues for adding to the industrial capability of the USA will be forthcoming.

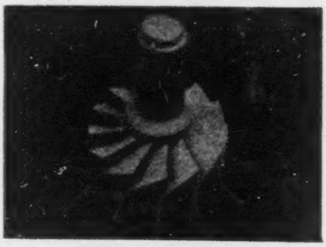


Figure 17. Ford Ceramic Bladed Turbine Rotor.

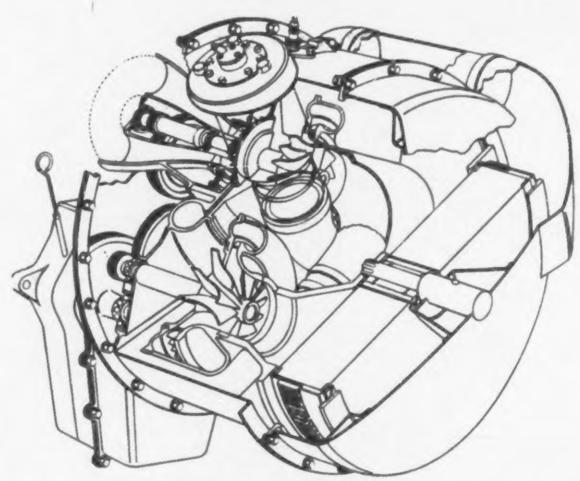
FUTURE TIME SCALE

John Boppart has outlined the activities planned for the next three years leading to the final assessment of the ceramic engine in late 1985, providing we continue to progress on the technology as we plan to. There is of course, a major step between a prototype running in the laboratory and a production unit — the achievement of a feasible design and processing operation that will enable a cost competitive unit to be offered to customers. At Ford we foresee that the earliest opportunity when we must plan to achieve an effective end product is in the early years of the 1990's. Throughout the progressive development of laboratory based techniques for producing the ceramic parts for the AGT, those concerned have kept an eye open for the possible routes to production, perhaps using processes not attempted as yet in the prototype work. We are not short of ideas on how to proceed in this next phase, but these are not being developed into feasible processes at this stage. The routes will, therefore, remain as ideas throughout the completion of the present program because of the financial limitations, appropriate to the objectives of the present studies, that are foreseen. In summary, much effort will be needed to achieve a successful follow-on program, aimed initially at production feasibility in a pilot phase, if we are to produce the AGT in cost-effective quantities in the 1990's.

Detroit Diesel Allison
Division of General Motors Corporation

EDR 11367

Statement of General Motors Corporation
on
Department of Energy Advanced Gas Turbine Technology Contract
to the
House Subcommittee on Transportation, Aviation and Materials
of the
Committee on Science and Technology



presented by
Harold E. Helms
Acting Chief Engineer--Advanced Gas Turbines
Detroit Diesel Allison Division
General Motors Corporation

24 February 1983

HAROLD E. HELMS
Acting Chief Engineer--Advanced Gas Turbines

Education

B.S. in Engineering Mechanics, Purdue University, 1948
M.S. in Engineering Mechanics, Purdue University, 1950

Work History

1952 to Date: Detroit Diesel Allison (DDA)
Division of General Motors Corporation
Indianapolis, Indiana

- o Acting Chief Engineer--Advanced Gas Turbines
- o Chief Project Engineer--AGT/CATE Programs
- o Chief--Regenerator Projects
- o Program Manager--NASA QCSEE Program
- o Chief--Analytical Mechanics
- o Section Head--Stress and Heat Transfer
- o Supervisor--Rocket Nozzles & Cases
- o Deputy Leader--DDA/Rolls Royce Joint Project
- o Senior Project Engineer--T40 Engines, T56 Engines

1950 to 1952: Engineer, Argonne National Laboratory, Lemont, Illinois

Responsibility/Experience

Mr. Helms is responsible for advanced gas turbine engines at DDA.

The AGT/CATE programs conducted for DOE/NASA were planned and directed under Mr. Helms's leadership of the DDA, Pontiac, Carborundum, GTE, Corning team. Ceramic materials technology is the major thrust of these projects.

Regenerator systems for the industrial gas turbine project (404/505/605) were directed by Mr. Helms. This included advanced work with Harrison Radiator Division, Coors Porcelain, Corning Glass Works, Pure Carbon Company, and POCO Graphite Company.

The NASA Quiet, Clean, STOL Experimental Engine (QCSEE) program was managed by Mr. Helms. The team members included Douglas Aircraft, Lockheed Aircraft, Hamilton Standard, Rohr Company, NASA Ames, NASA Langley, and NASA Lewis Research Center.

Analytical Mechanics, including stress analysis, heat transfer, vibrations, weights, and computer analysis, were directed by Mr. Helms.

Turbine cooling, including convection, film, and transpiration cooling methods were implemented and developed under Mr. Helms's direction. Lamilloy, an Allison invention, was conceived and developed under his direction.

Mr. Helms prior experience includes work on various rocket motor cases and nozzles, turboprop, turbofan, turbo-shaft, and turbo-jet engines at Allison. Mr. Helms worked on the original reactor project for the Nautilus submarine under the cognizance of Captain Rickover, USN.

Mr. Chairman, thank you for this opportunity to present a status report on the Detroit Diesel Allison (DDA) "Advanced Gas Turbine Technology Project" supported by Department of Energy funding and contracted through the NASA Lewis Research Center. I am Harold "Gene" Helms, Acting Chief Engineer--Advanced Gas Turbines, and this project falls into my area of responsibility.

Objectives--Key Technologies

The Advanced Gas Turbine (AGT) Technology project has objectives which include the demonstration of a "proof of concept" automotive engine that will have the capability of producing 30% improvement in fuel economy in a 1984 Pontiac Phoenix automobile; will operate on alternate fuels; and will meet 1985 automotive emission requirements. In addition, competitive initial and life cycle costs, reliability, performance, and noise and safety criteria for 1985 automobiles are goals for the advanced gas turbine power train. Figure 1 shows the project objectives and the candidate application for the proof of concept engine. The automotive application dictates strong emphasis on marketplace

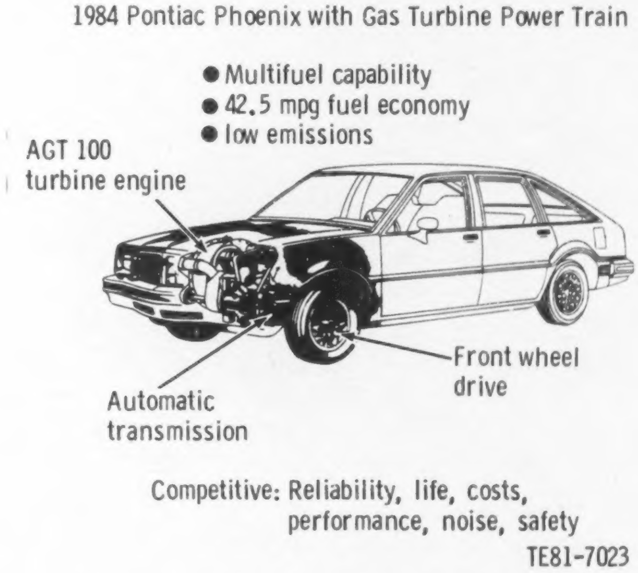


Figure 1. Objectives and AGT 100 vehicle.

criteria in developing required technologies. These criteria are cost, performance, and reliability. DDA carefully applied these criteria in identifying key technology areas, proof of concept engine geometry, and overall technical approacn in meeting objectives.

Two key technology areas being addressed which are pacing the technical progress of the AGT project are:

1. ceramic materials and
2. small-scale aerodynamics.

CERAMIC MATERIALS

Ceramic materials are the new and innovative technical area which will determine the future practicality of automotive gas turbines. It is necessary that ceramics replace the prohibitively expensive high-temperature capability superalloy metals currently used in gas turbines. Superalloy costs are prohibitive because they contain significant levels of strategic materials such as cobalt, chromium, nickel, molybdenum, tungsten, and manganese. None of these strategic materials are found in the silicon carbide, silicon nitride, oxides, and silicates used in the AGT project. In addition, the ceramics possess high temperature capability in excess of superalloys.

AERODYNAMICS

Small scale aerodynamics are vitally important because the automotive gas turbine engine has airflow components smaller than ever before employed in a high performance production turbine. Simultaneously, the automotive application requires high component efficiencies over a broad power range, with the highest efficiency required at part speed and power conditions. The average automobile power use is 14 hp for a 100-hp engine, and most automobiles never use maximum power. This contrasts from aircraft, industrial, and heavy duty turbine engines, which operate predominately at 50% to 100% power level.

ENGINE

Turbine experience has shown that technology is only valid when demonstrated in an actual, useful engine environment. For this reason, proof of concept engines are included in this project to provide a valid environmental evaluation and prove that ceramic and aerodynamic technologies have been established in sufficient depth to show potential future usefulness for industry. Detroit Diesel Allison has designated its proof of concept engine as the AGT 100. Figure 2 shows the first AGT 100 engine ready for test. This engine weighs

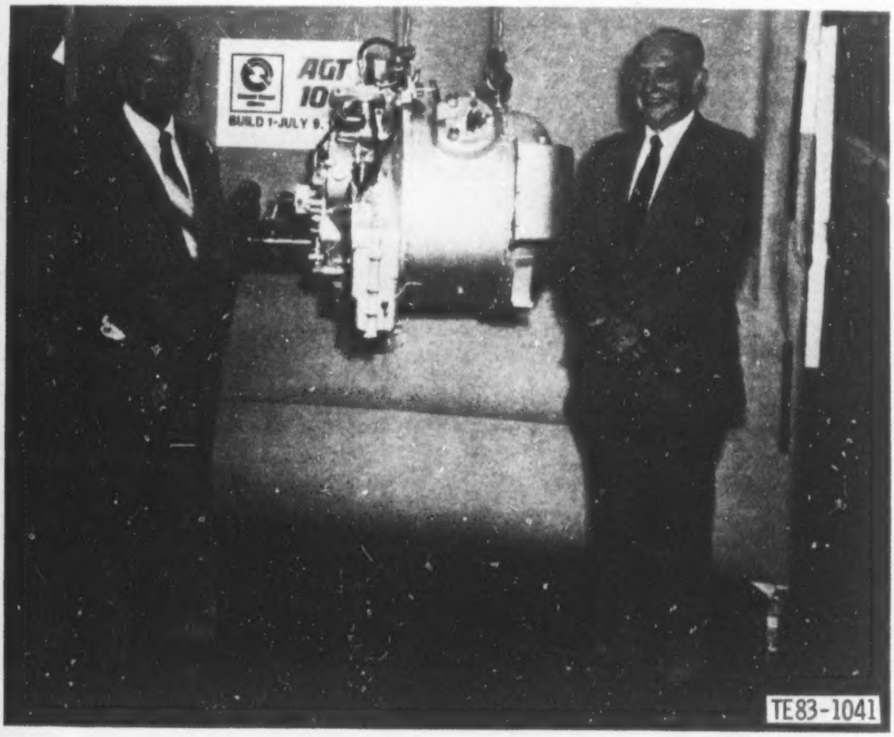


Figure 2. AGT 100 engine.

less than 300 lb and develops 100 hp. It is a two-shaft engine designed to operate with both manual and automatic transmissions and will fit either an X-body or A-body engine compartment interchangeably with 2.8 liter V6 or 2.5 liter L4 spark ignition engines. These General Motors cars are new mid-size, front wheel drive, 3000 lb weight class vehicles that are rapidly replacing rear drive automobiles.

PROJECT TEAM

Pontiac Motor Division of General Motors Corporation is a partner of Detroit Diesel Allison in the AGT project, providing producibility, marketing, and cost analysis experience required. This partnership has produced an engine design that has the potential to meet marketplace requirements for cost effectiveness.

Detroit Diesel Allison has continuously worked on projects that emphasize development of ceramic materials technology under Department of Energy/NASA funding since 1976. The Ceramics Applications in Turbine Engines (CATE) project helped to establish the feasibility of ceramic structural components during 9400 hours of ceramic component engine testing. The AGT 100 project enlarges the CATE ceramic technology base and addresses the necessary, cost effective, ceramic component processing technology. The following companies have made either ceramic test specimens or turbine engine components in the CATE and AGT 100 programs:

The Carborundum Company, Niagara Falls, New York
The Corning Glass Works, Corning, New York
GTE Laboratories, Waltham, Massachusetts
Pure Carbon Co., St. Marys, Pennsylvania
Annewerke Division of Ceranox Co., West Germany
Rosenthal Co., West Germany
Feldmuhle Co., West Germany
Kyocera-U.S. Division of Kyoto, Japan
NGK Insulator Co., Japan
AiResearch Casting Company, Torrance, California

DDA has endeavored to conduct advanced ceramic component processing development activities principally with Carborundum Co., GTE Laboratories, and Corning Glass Works, who are all American suppliers.

PROJECT STATUS

In the past year, the first AGT 100 engine has been assembled and testing has been initiated. Nine ceramic components were incorporated in the first engine build as a result of earlier successful rig testing. Six hours of testing has been completed and has confirmed the earlier rig aerodynamic evaluations of individual components with regard to efficiency, leakage, pressure drop, and temperature. Sophisticated engine and component instrumentation has helped to identify component interactions and minor mechanical deficiencies.

Testing during fiscal year 1983 will enable DDA to introduce ceramic turbine rotors and scrolls in the engine in fiscal years 1984 and 1985. One engine is now being tested; a second engine will be assembled and ready to test by May 1983; a third engine will be ready for testing in January 1984; and the fourth engine will be ready for test by October 1984. Four engines will provide adequate capability for orderly ceramic component evaluations, for characterizing engine performance, and for initial assessments of ceramic component reliability.

More than 1500 hours of component test evaluations have now been achieved in the AGT 100 project. These test hours include qualification testing of silicon carbide gasifier and power turbine vanes, silicon carbide combustors, aluminum-silicate regenerators, and lithium-aluminum-silicate regenerator bulkhead. These parts were successfully run in our first engine. Carborundum Company has been very active in the engineering exchange of parts and data with DDA to permit the establishment of proper processing parameters for silicon carbide engine rotors and scrolls. GTE has done the same on silicon nitride rotors. Figure 3 shows the unique ceramic component geometries that have now been made and are now being evaluated in the AGT 100 project. Silicon carbide is the material receiving major emphasis in the DDA project.

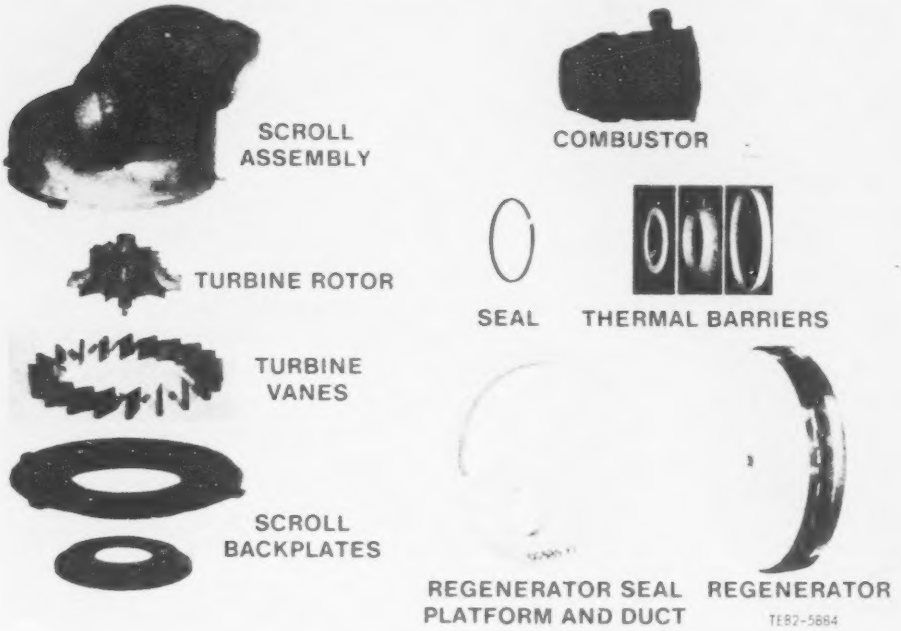


Figure 3. AGT 100 ceramic components.

Ceramic rotor fabrication was considered a major processing problem at the start of this project. The Carborundum Company was the first to make a breakthrough in processing technology and has now produced many injection molded and sintered silicon carbide rotors for DDA. Figure 4 is a photograph of one of these rotors made at the instant of rotor burst while rotating at 130% of design speed or 111,000 revolutions per minute. This type of photography plus new nondestructive acoustical measurement techniques are beginning to yield critical information on how to improve processing and reliability of ceramic components. Much additional work is necessary to achieve production ready ceramic components and required processing and inspection specifications.

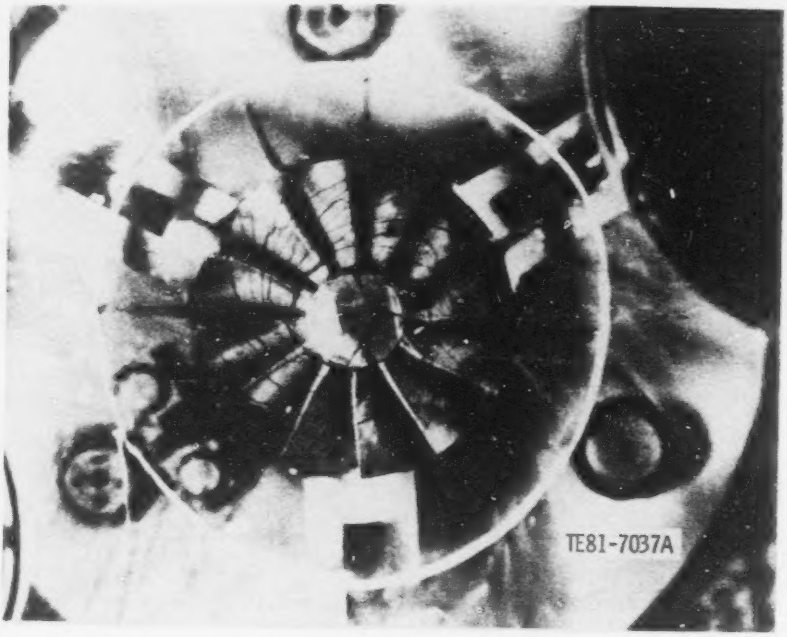


Figure 4. AGT 100 rotor burst test--130% design speed.

Initial aerodynamic performance testing has been completed on compressors, combustors, turbines, and regenerators. The results of these tests provide a high level of confidence that program goals for fuel economy, maneuverability, and emissions can be met using the small components required for the AGT 100. The emission levels required to meet 1985 standards are shown in Figure 5 by the dotted lines for CO and NO_x. Measured CO and NO_x values are significantly better than required. This suggests a less expensive combustor geometry eliminating variable combustor parts. Alternate fuels such as gasoline, alcohols, methanol, and even natural gas have the potential to work with this combustor with either few or no changes to the engine.

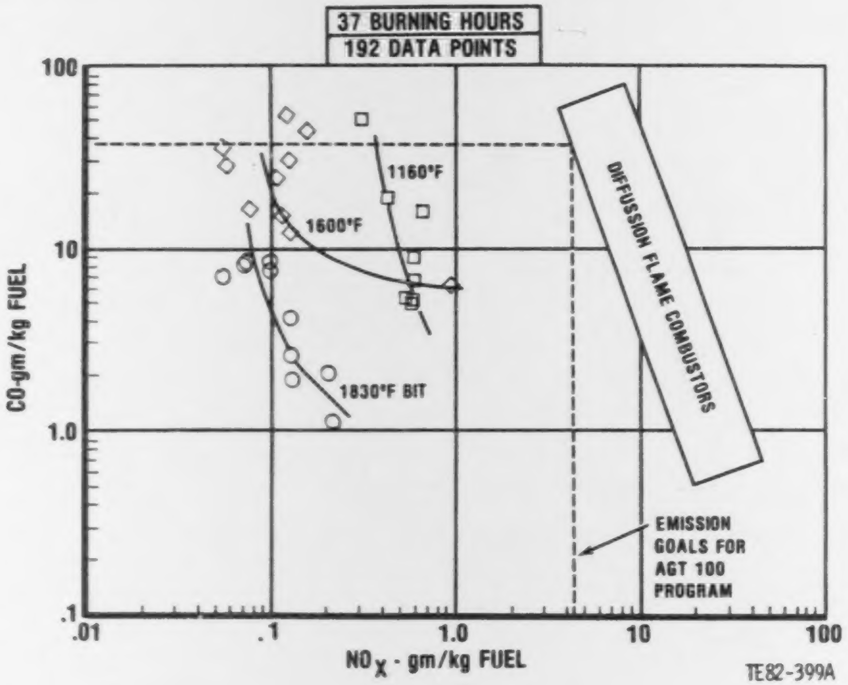


Figure 5. AGT 100 combustor rig test emission results (diesel fuel No. 2).

A cost analysis by Pontiac Motor Division on the AGT 100 engine indicates that, in production quantities, the turbine may have a price premium close to that of a diesel engine relative to gasoline engines of comparable performance. There are unknown factors that could affect this conclusion since ceramic component processing is still in the research stage. While cost is an important factor and could ultimately determine whether the AGT 100 succeeds in the marketplace, the achievement of structural reliability is the primary concern at this time. Our engineers are nevertheless sensitive to cost considerations and are alert for an opportunity to reduce component costs without sacrificing performance or quality.

SCHEDULE AND FUNDING

The AGT 100 project originally consisted of a 65 million dollar, 68-month program. It currently is a 57.7 million dollar, 72-month program. Fiscal years 1983, 1984, and 1985 remain to be completed. Vehicle testing has been eliminated from the government sponsored part of the project. Successful completion of the engine and technology program will provide strong motivation for future vehicle evaluations by General Motors. Figure 6 shows a schedule for the revised AGT 100 project.

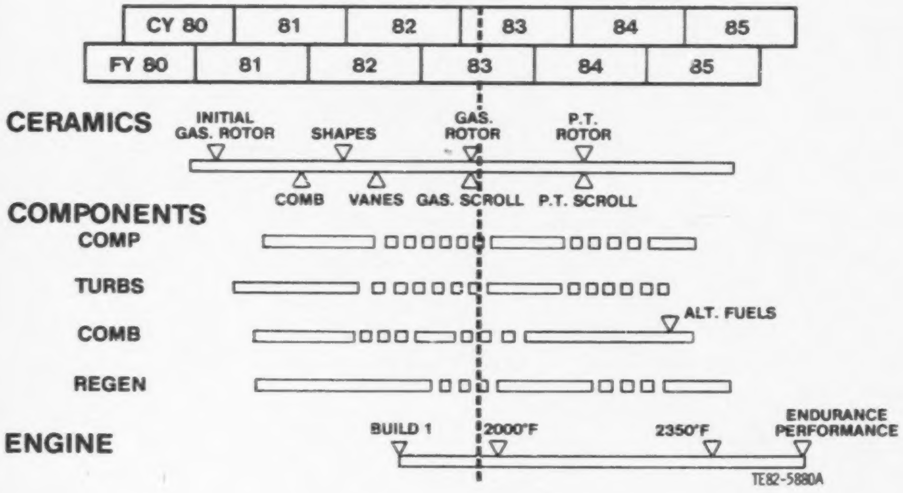


Figure 6. AGT 100 schedule.

In November and December 1982, DOE/NASA initiated a convergence action to select between the DDA/Pontiac and Garrett/Ford teams for the remainder of the program. In early January, this year, DDA was advised that convergence was halted and sufficient funds had been provided to continue both contracts through fiscal year 1983. DDA certainly concurs with this action.

To continue the AGT 100 project to completion requires a funding level of approximately 33 million dollars. DDA expects to cost share 10%-12% of this amount with the government share at approximately 30 million dollars. DDA believes that this funding level can carry the project to a successful demonstration of objectives by the end of 1985. We have discussed with NASA requirements for government funding of 8.7 million dollars in fiscal year 1983, 12.0 million in fiscal year 1984, and 9.3 million in fiscal year 1985.

OUTLOOK

A natural follow on activity to this project will be enlarged ceramic component applications in diesels and spark ignition engines and evaluation of the new gas turbine engines in automobiles. DDA is considering the application of an enlarged AGT 100 engine for trucks, buses, boats, and other heavy duty applications.

On 25 March 1981, Mr. H. L. Smith, then Vice President of General Motors and General Manager of the Detroit Diesel Allison Division, addressed a letter to your subcommittee which stated in part: "The U.S. Government, through DOE funding, has stimulated industry to address the basic development of a technology which promises to have far reaching international impact, at a time when risk is high and demands for American corporate funding are at unprecedented levels."

This continues to be the situation today, except that current assessments show efforts to develop "fine ceramics" in Japan, which are subsidized by the Japanese government, may far exceed the United States development effort. Similar efforts in Germany, Sweden, and other countries are in progress. The foreign efforts may constitute a threatening situation to the U.S. ceramic industry.

Your interest in this subject is invited because the infrastructure of the structural ceramics suppliers remains small and tenuous. No existing market supports the expensive research and development efforts required of U.S. ceramic suppliers, and they may find it impossible to compete with the foreign research and development effort. If foreign dominance prevails in structural ceramics, their broad potential application in heat engines and other devices could have a significant impact on U.S. industry.

Mr. Chairman, that concludes my prepared remarks. Thank you for your attention, and I will be happy to respond to any questions you or the subcommittee members may have.

APPENDIX

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INTERNATIONAL UNION, UNITED AUTOMOBILE, AEROSPACE & AGRICULTURAL IMPLEMENT WORKERS OF AMERICA—UAW

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MAR 1 1983

February 21, 1983

Congressman Dan Glickman, Chairman
Subcommittee on Transportation, Aviation and Materials
House Committee on Science and Technology
2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. Chairman:

The UAW is submitting this letter for the record of your Subcommittee's February 23-24, 1983 hearings on the U.S. Department of Energy's transportation program and its FY 1984 funding. We appreciate your invitation to do so.

As we testified before your Subcommittee in July 1981, and as we wrote you in February 1982, we strongly believe that there needs to be much more, not less, government-sponsored automotive R&D. As we have noted before, we are in a period during which the U.S.-based auto producers must concentrate spending on new, lighter models, rather than on long-term basic power plant research programs.

This market-dictated emphasis may well yield outcomes that are bad for this nation. There is no reason to believe that the short-term cash position of private entities will permit the long-term investments needed to maintain a competitive U.S. auto industry. Hence a major role for a public R&D effort.

We would also note that the nation has a large stake in seeing that the commercialization of U.S.-generated automotive technology occurs in this country. By doing so, we earn a return on public and private R&D investment alike. The Administration's proposed DOE transportation budget illustrates its utter failure to grasp the aforegoing realities. Believing that only a passive, penny-wise and pound-foolish government is consistent with the "free market," it proposes to zero out all U.S. Stirling engine research after FY 1983 and to reduce (and concentrate in one contractor) gas turbine work.

This would be a disaster. In the case of Stirling work, it would be to pull the plug on research that is within a few years of proving an efficient, multiple fuel-compatible, clean, quiet power plant that could replace many of the three million - plus imported engines planned for domestically-assembled cars and light trucks. The MOD I engine is "running up to all expectations — and not just on test stands" (Popular Science, Jan. 1983), and the MOD II — if brought to commercialization in the 1985-87 time frame — can leapfrog Japan in heat engines, despite their far better-funded Stirling program. Zeroing out U.S. Stirling contract work would send MITI a message it wants to hear: the U.S. has decided to cede the next generation of heat engines to Japan.

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It would be similarly irrational to reduce gas turbine contract R&D. Plans to concentrate remaining resources with a single contractor are, if nothing else, premature. Until MOD II demonstration in late FY 1985, at least that part of gas turbine R&D that involves ceramics needs the diversity of several lines of attack.

If the U.S. wants a competitive auto industry, it needs to decide to have one. A key element in that decision is government-funded power plant RD&D. Despite insufficient past federal support, there are signs — in Stirling work, in ceramics, and in electric vehicles (especially batteries) — that some of our 1970s spending is about to bear fruit. At a time when every other significant industrial, and several industrializing, countries are protecting, nurturing, subsidizing, and rewarding investment in the automotive field, it would be the height of ignorance for the United States to risk our auto industry's future in blind homage to private sector self-sufficiency.

Again, our thanks for providing us this opportunity for UAW comment on DOE's FY 1984 transportation program.

Sincerely,

Daniel Luria
Research Economist

Dick Warden
Legislative Director